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EXPLOSIVES SAFETY SEMINAR

VOLUME I

HYATT REGENCY HOTEL

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PREFACE

This Seminar is held annually as a medium by which there may be a free exchange of information regarding explosives safety. With this idea in mind, these minutes are being provided for your information. The presentations made at this Seminar do not imply indorsement of the idea, accuracy of facts presented, or any product, by either the Department of Defense Explosives Safety Board or the Department of Defense.

P. F. KLEIN
Captain, USN
Chairman

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WELCOME ADDRESS

Captain P. F. Klein, USN
Chairman
Department of Defense Explosives Safety Board

Ladies and Gentlemen

It is with considerable pleasure that I welcome you to this 15th Annual Explosives Safety Seminar. In the past, the sessions have been widely acclaimed in the explosives safety community of the United States and I sincerely hope that the results of this seminar reflect previous standards. It is always our purpose to provide professionally stimulating and informative material for these gatherings and the agenda which we have drawn up for this year is in my view a very good one. I am, of course, the recently appointed Chairman of the Department of Defense Explosives Safety Board. I look forward to this as an interesting and challenging assignment and I also anticipate meeting and talking individually with as many of you as possible during the course of this seminar and my tour as Chairman. I would also like to particularly welcome several of our professional friends from other countries: Australia, Brazil, Canada, France, Germany, and the United Kingdom. Before proceeding with the formal agenda of the meeting, let me introduce the designated members of the Explosives Safety Board - From the Department of the Army, Mr. Walter G. Queen - Department of the Navy, Captain J. N. Howard - and the Department of the Air Force, Colonel J. P. Huffman, Jr. I also have a newly assigned Department of the Army representative on the Secretariat - Colonel Philip G. Kelley, and I am expecting the assignment of an Air Force officer to the Secretariat in the weeks ahead.

A NEW APPROACH TO EXPLOSIVES SAFETY

Honorable Arthur I. Mendolia
Assistant Secretary of Defense (Installations & Logistics)

Ladies and Gentlemen

I appreciate the opportunity to speak to you today at this 15th Annual Explosives Safety Seminar. I am told that as many as 600 of you have participated in the various technical sessions of this Seminar the last two days. This is truly an amazing number, and by far the largest group which has ever attended. I am particularly pleased with this interest because the accidents of the past year, with which I am sure you are all familiar, are certainly cause for us to look carefully at our past procedures, and to minutely examine all facets of explosives safety.

Too often in such introspection we tend to look only at a minute listing of procedures and to refine the smallest details of our actions while neglecting the overall aspects of what we do. Today I want to suggest a new approach to explosives safety -- one which would change not the details, but our whole concept of production and use.

What is this approach? The same one industry is now using -- the same thing that is replacing dynamite -- almost has replaced dynamite as a commercial explosive. It is ammonium nitrate. And if I detect a few sighs or grimaces at that suggestion, let me assure you that I could list without much thought a large number of objections to the use of ammonium nitrate as a military explosive. We all know the objections, but let's look at it differently -- let's say, "What if we could use it?"

Consider our ammunition plant modernization program. A program approaching 5 billion dollars with possible expenditures of one-half billion dollars a year.

To appreciate the size of this program, one must realize that it is almost twice the original cost of all of our Government-owned, contractor operated plants, which were built in World War II. It is approximately half the total replacement value of these plants today.

A substantial portion of the total program is involved with upgrading the production lines of explosives and the acids needed for those lines. The mix of explosives manufacturing capacity is based on our projections of need considering the preferred fills, mostly TNT and RDX, for our future munitions, and some acceptable alternatives to these so-called preferred fills.

This concept, that there are acceptable alternatives to the preferred explosives, has in itself resulted in very large savings over the costs of building plants that would completely meet all of our requirements with preferred explosives, and it allows a broadening of the production base with some increased reliance on industry which would not be possible otherwise.

These are very desirable results. Other extremely fortunate results of the modernization program are the increases in safety achieved and the reduction of pollution.

But, think what we could do if we used ammonium nitrate. I estimated the other day that we could build a 500,000 ton per year ammonium nitrate plant for 10-12 million dollars. From billions down to millions. And we might not even have to build plants. Ammonium nitrate production capacity is probably in excess of our total needs for the next several years right now.

But, you are here to discuss safety -- not plant capacity or dollars as such -- and ammonium nitrate is safe. Safe to produce -- safe to transport -- safe to use.

Safe to transport -- yes. The explosive gel is usually made by mixing ammonium nitrate with another nitrate, such as sodium and a sensitizer. And in commercial applications, they are not mixed until its time to use them. We need not bring explosives to the job site -- we bring non-explosives in tank trucks and mix them in a portable manufacturing plant as they are poured down the hole. No magazines to build and guard. No explosives at all on the site, except what is in the holes.

Militarily? Well, could you imagine mixing the explosive and putting it in the bomb just before you put the bomb on the airplane? Would you consider shipping bulk non-explosive materials to a theatre such as Vietnam and manufacture the explosive on site? We did have some accidents in Vietnam, and we did lose ammunition to enemy attack when it contributed to its own destruction. Suppose it had not been able to explode until we wanted it to explode.

What about after it is mixed? How safe is it then? By almost any test -- drop, fire, high speed bullet -- ammonium nitrate is 10 to 100 times safer than TNT or RDX, or a number of other explosives. You know it is that safe and you know that that is why it is replacing dynamite. Now it is probably not so absolutely safe that you gentlemen would let us throw out the table of distances but, if we don't have to mix it until we need it, our total explosives storage requirement would be so far reduced that almost the same effect would result. And, with land costs what they are today, one acre that can be dropped from a safety zone and put to other use may be worth many thousands of dollars.

I sense that you may not be satisfied unless I list some of the objections to ammonium nitrate that have caused it to be rejected as a standard military explosive.

Shelf life -- as now mixed, the best shelf life we could expect would be 2 or 3 years.

Also, its very safety derives from the fact that it is difficult to detonate -- a military liability certainly.

Its detonation rate is low and, therefore, fragmentation effects are less than desirable.

It was formerly thought to be undetonatable in small diameter sticks and small caliber munitions.

It is perhaps 10 percent less effective in producing blast than our preferred explosives.

But, are these objections valid and, if so, are they insurmountable? I think not. In the past two years, many advancements have been made in the use of ammonium nitrate -- such as detonating in less than one inch sticks -- formerly thought impossible. Is 10 percent less blast effect unacceptable when we can afford to produce one and one-half to two times as much of it as of other explosives -- perhaps yes -- if the delivery system is the governing factor. And perhaps the low fragmentation effect is also a valid argument against, right now.

But we have improved shelf life. We have improved detonability. Can we speed up detonation rate? Can we improve blast effects?

Today, ammonium nitrate is almost acceptable as a military explosive. It would just take a little more work to make it acceptable.

And, gentlemen, what if it were ok? What if we could use it?

Think about how easy it would make your job. We could eliminate explosive accidents in transportation. Think how easy that makes the task of the regulatory agencies, establishing transportation standards. Think how the public benefits in increased safety and less cost.

Think of the taxpayer dollars saved -- not only in reduced plant cost -- but in production costs which make ammonium nitrate only two-thirds as expensive to produce as TNT. And as a correlary, remember -- reliance on a Government-owned plant that is very expensive to maintain through long periods of non-use is inherently less desirable than reliance upon an easily converted privately-owned production capacity that would operate at a profit producing other materials when not needed for munitions. The benefits could be really amazing.

The questions that come after "what if we could?" are "can we?" and "should we?"

With those benefits, should we not. Should we not indulge in the research and study and the testing to overcome these problems? Suppose we spent 10 to 20 million dollars on research to improve it to the point of acceptability -- and saved the cost of a half billion dollar TNT plant by so doing. We would then be efficient Government administrators besides advancing the cause of safety.

The question I raise today is, "Are you who represent this money, this effort, this time -- are you directing your energies toward the right idea? Should you instead of looking for ways to make handling our explosives safer, be looking for a safer explosive?" Ammonium nitrate is one -- there might even be others.

I am sure that not all of you agree - but, please, don't leave here and say, "That fellow Mendolia gave a speech extolling the virtues of ammonium nitrate, and everyone knows we can't use that." Everyone may know we can't -- but ladies and gentlemen -- what if we could?

Thank you.

ESKIMO II AND FUTURE PLANS

R. G. Perkins
Department of Defense Explosives Safety Board
Washington, D. C.

The Department of Defense Explosives Safety Board has for several years been engaged in a program of evaluation and verification of the explosives safety standards published by the Secretary of Defense. Heavy emphasis in this program has been placed on reducing the separation distances required between magazines.

At the seminar last year we presented a film report, ESKIMO I, on this program which summarized a test of standard doors and headwalls of steel arch magazines.

The second major test in the current series was executed in May of this year. We think, again, you will be interested in a complete film report which described the technical details and the results. (showed film)

As described in the movie, the ESKIMO II test left us with some useable capital assets, Figure 1.

In spite of the overloading of the doors and headwalls, all of the steel arches in the test array were in excellent condition.

Had we used acceptor explosives in the control igloo, it might have been destroyed. Pressure measurements have shown that the blast loading on the control igloo was somewhat more severe than on the west igloo, where some of the acceptor explosive charges burned, Figure 2.

The oval arch test structure in this layout was built to the full length of our standard igloos - 80' - in order to permit an eventual test of it against lateral blast loading such as might be expected from a maximum event in a parallel igloo of the same size.

Because of the number and position of remaining arches in the area we were also able to design a test in which we could expose several additional headwalls to a suitable donor charge for further evaluation of the Board's intermagazine distance tables.

The test, planned for early in the first quarter of 1974, will look like this in the near field area, Figure 3.

It is built around the principal target, or acceptor, the oval arch igloo. A new donor and a new acceptor igloo will be constructed parallel to the oval arch. The three igloos will be separated by 88 feet: $125W^{1/3}$ for 350,000 pounds of high explosives.

LAYOUT OF TEST STRUCTURES FOR ESKIMO II

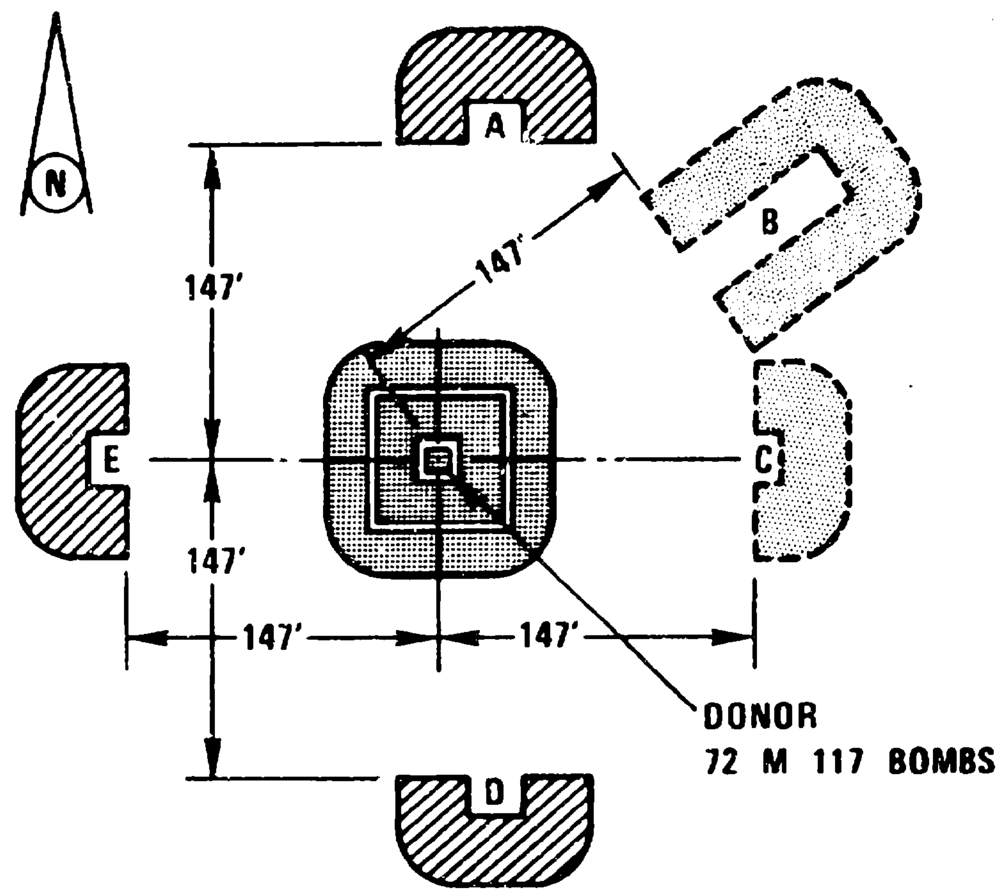


Figure 1

NON-CIRCULAR STEEL ARCH

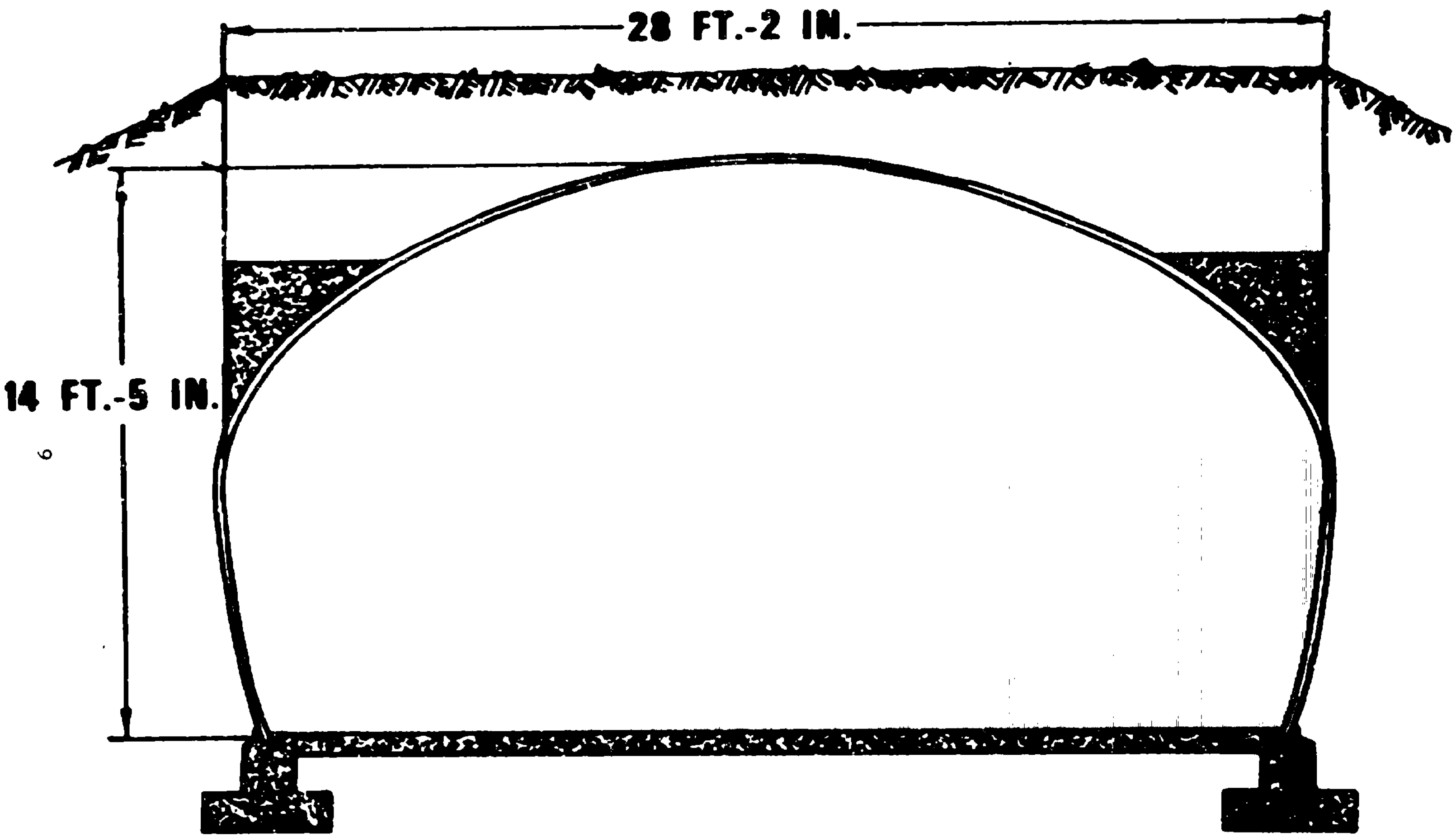
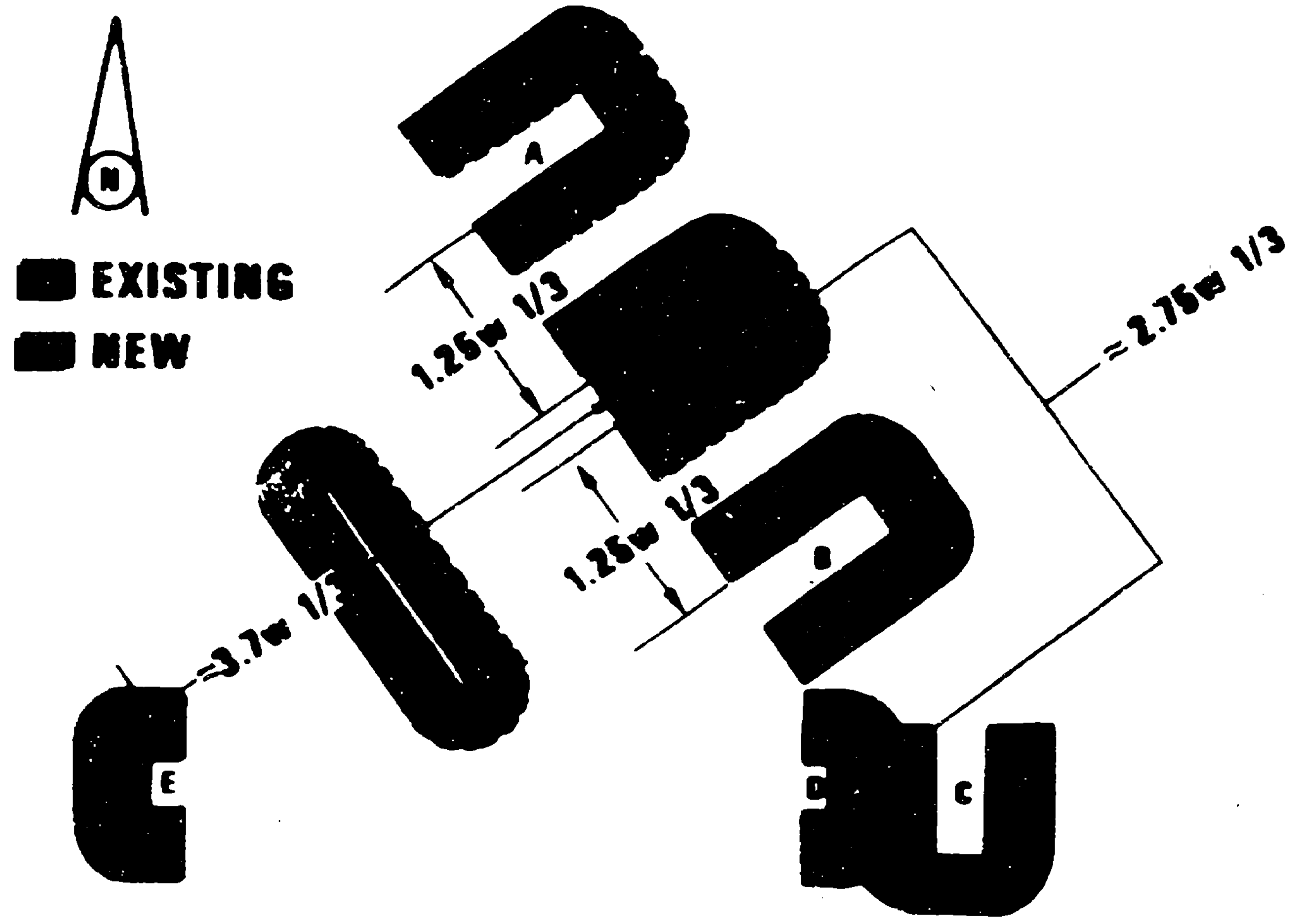


Figure 2

LAYOUT OF TEST STRUCTURES
ESKIMO III



The two new igloos, each eighty feet long, will be of a type not previously included in tests sponsored by the Board but recommended by one of the Military Departments for construction economy reasons. The arches will consist of deep corrugated 14-gage steel instead of one-gage structural plate required for this size structure in present standards, Figure 4.

The present DoD igloo separation standards are based upon a presumption that the earth cover rather than the structural strength of the arch is the most important factor in limiting the risk of communication between adjacent arch type magazines, Figure 4.

A donor charge of 350,000 pounds of tritonal in 750-pound M117 bombs will be used, Figure 5.

Bombs will be stacked in accordance with the Department of the Army standard plan for this item in its usual palletized storage configuration.

The size of the donor charge is large enough to justify extrapolation of the results to the current limit for high explosive magazines. Also the tritonal filler and charge-weight ratio of these bombs are such that the results can be applied to our "real world" storage problems with a high degree of confidence. By contrast, the ESKIMO I event was somewhat of an undertest because it used TNT in 155mm projectiles, an item with a very low charge to metal ratio. The results thus could be used with confidence only with items having a similarly low charge to metal ratio, Figure 6.

The major emphasis in ESKIMO III will be to:

a. Evaluate the oval steel arch at the standard side-to-side spacing of $1.25W^{1/3}$.

b. Compare the light weight, deep corrugated steel arch with it and with the previously tested steel arch of cylindrical shape, and thus

c. Further examine the importance of earth cover versus arch strength in limiting communication.

Secondary magazine exposures will be at acceptor positions shown to subject various headwalls and doors to the effects of detonation of a full igloo at or near the minimum permitted distances, Figure 6.

Acceptor C affords an opportunity for a direct test using the improved single-leaf sliding door on a sound, existing specimen of the standard headwall for the steel arch magazines. The exposure will load the door and headwall obliquely at very nearly the $2.75W^{1/3}$ distance now specified in the standards for side to front exposures. The oblique orientation should reduce the severity of the exposure but it is difficult to tell how much with certainty.

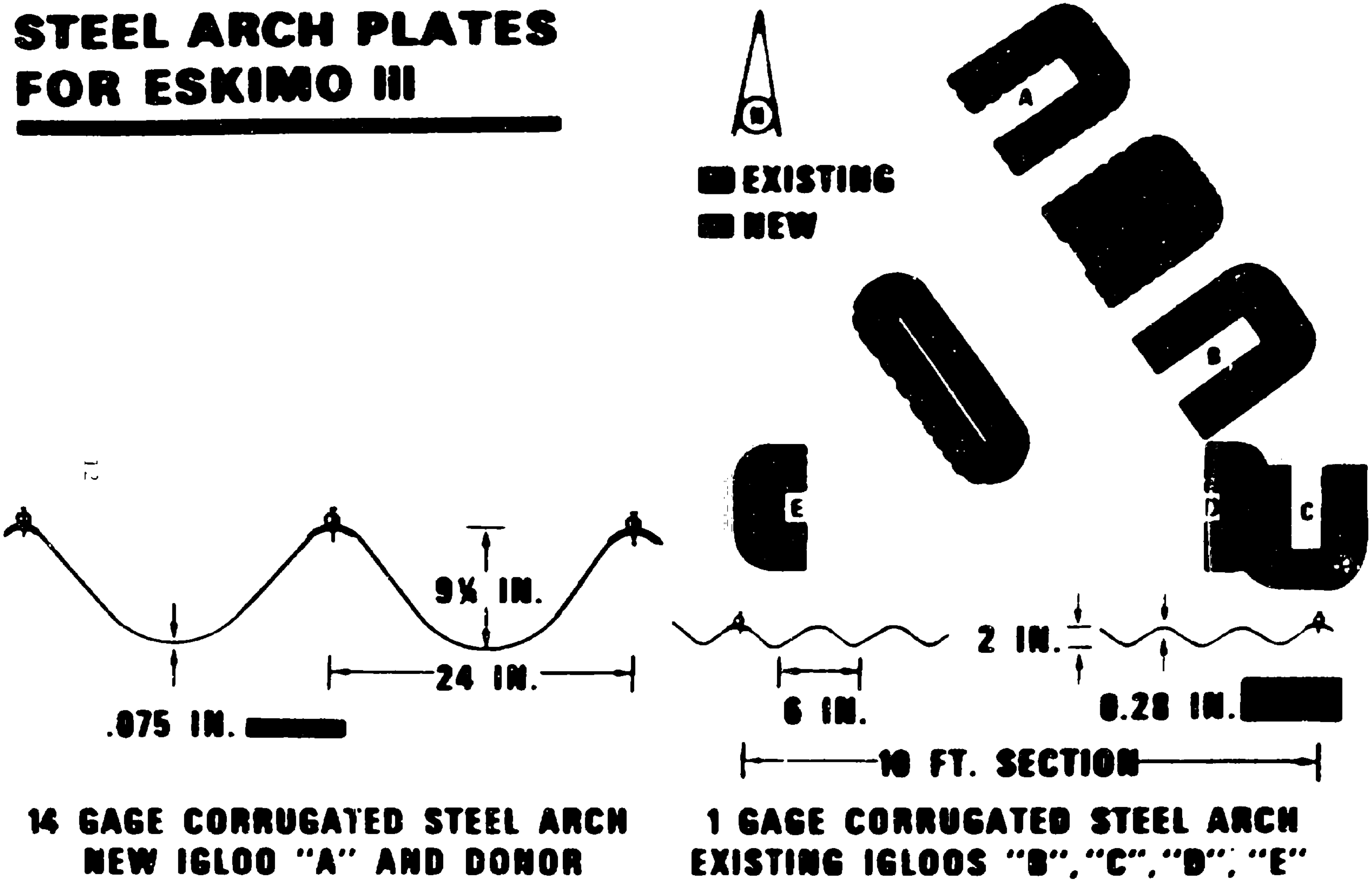

STEEL ARCH PLATES
FOR ESKIMO III
N
EXISTING
NEW
A
B
C
D
E
9¼ IN.
24 IN.
.075 IN.
6 IN.
2 IN.
0.28 IN.
10 FT. SECTION
14 GAGE CORRUGATED STEEL ARCH
NEW IGLOO "A" AND DONOR
1 GAGE CORRUGATED STEEL ARCH
EXISTING IGLOOS "B", "C", "D", "E"

Figure 4

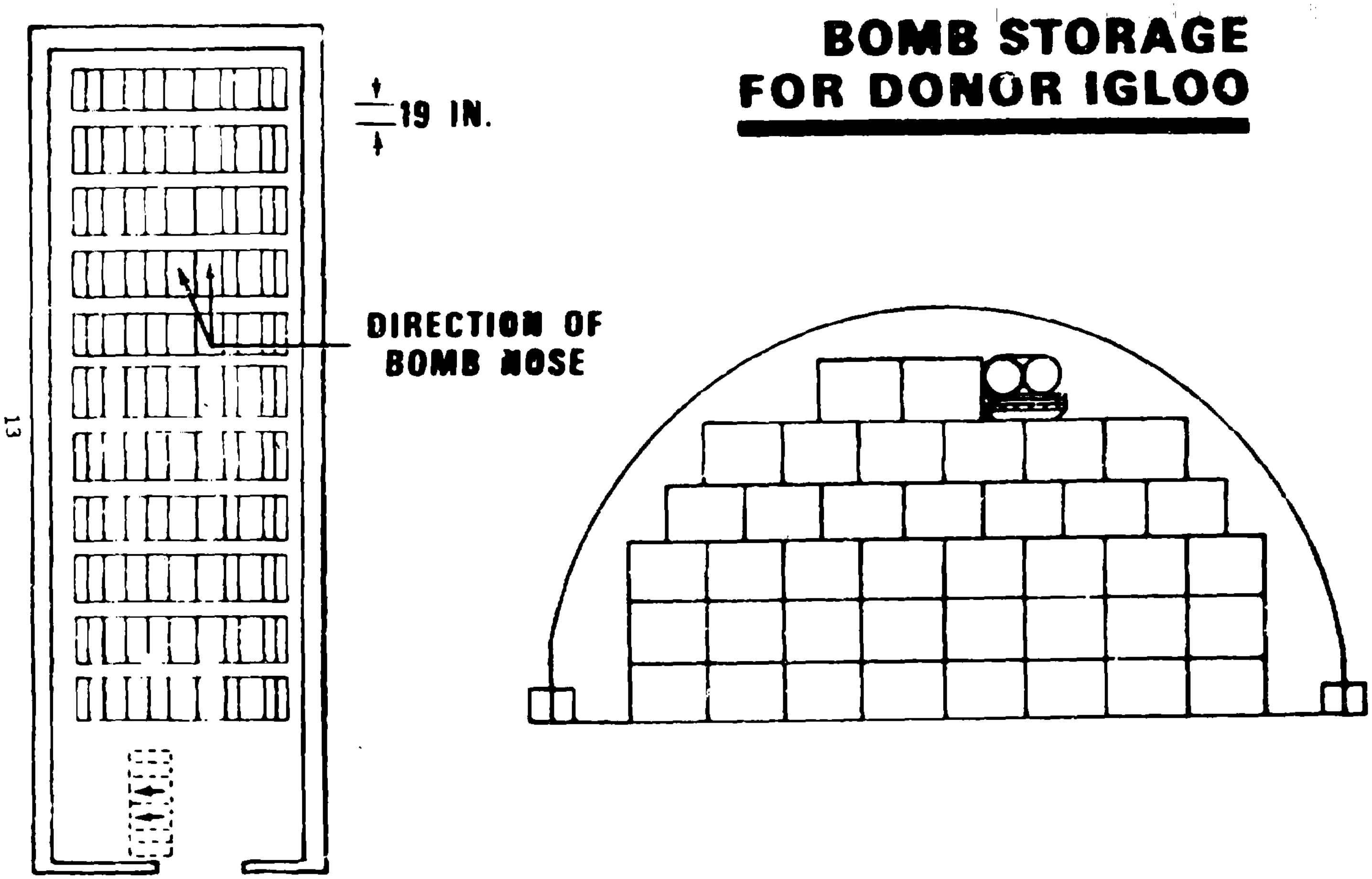
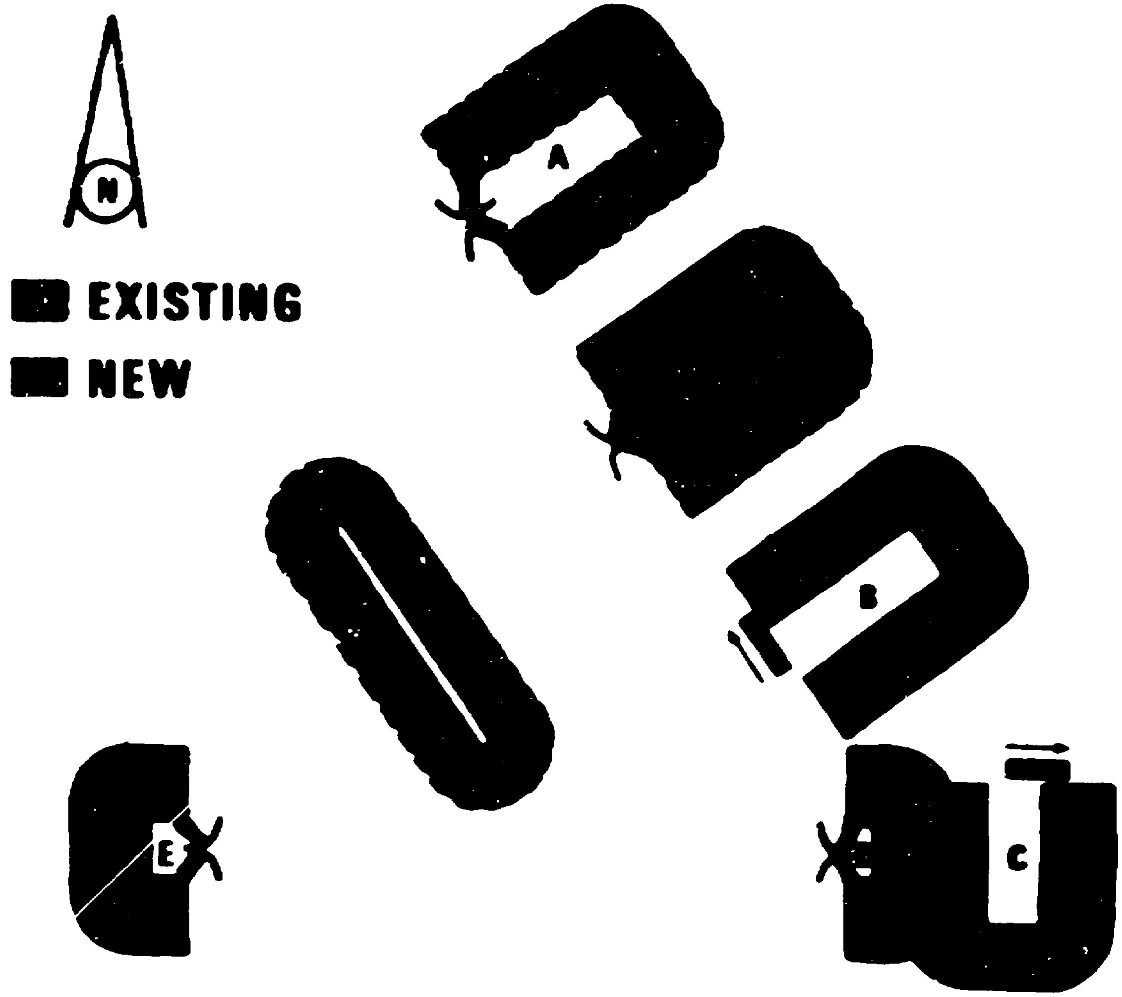


Figure 5

DOORS FOR ESKIMO III STRUCTURES



Acceptor D will be a similar test of the standard steel arch magazine in the region where $1.25W^{1/3}$ would be permitted despite some degree of line-of-sight exposure of donor and acceptor headwalls. It is nearly at the dividing line of orientation angles at which the distance of $2.75W^{1/3}$ becomes applicable. A success at this exposure which is actually at about $2.55W^{1/3}$ would increase confidence in the standard and perhaps permit some further relaxation, at least on a special-case basis.

Acceptor E is a barricaded front-to-front exposure of two igloos at $3.70W^{1/3}$ for the 350,000 pounds of explosive contained in the donor charge. The current DoD standard for this situation is $6W^{1/3}$. This orientation was tested in ESKIMO I with failure at $2W^{1/3}$. The test of a separation midway between $2W^{1/3}$ and the untested $6W^{1/3}$ will evaluate whether the possibility exists of a worthwhile reduction of this standard distance for igloos and for substantial aboveground magazines or hardened operating buildings as well, Figure 7.

Because of the size of this event and the major importance it has with respect to magazine design, special instrumentation will be provided.

Incident peak pressure will be measured in front of each acceptor igloo at the ground level. Reflected peak pressure and impulse will be obtained from face-on gages set in the headwalls of each acceptor igloo.

A row of surface gages will be emplaced to measure the incident peak pressure over the earth on the oval arch igloo and Acceptor A which is to be used for comparison. Acceleration and displacement measurements will be made within these two igloos in order that, if they fail, the rapidity of failure can be used to estimate whether there would have been a risk of explosion communication to explosive contents.

We don't plan the use of explosive acceptors in ESKIMO III because preservation of the damaged structures for detailed physical examination appears to be of greater value than the simple "go," "no-go" indication that explosive acceptors would yield, Figure 8.

ESKIMO III will expose the window boxes and comparable automobiles to the igloo explosion at similar scaled distances to those used in ESKIMO II.

Both U.S. and NATO inhabited building distance.
Both U.S. and NATO public traffic route distance.

The most distant set of window boxes will be positioned at 1½ times NATO inhabited building distance, rather than twice as in ESKIMO II, because of the lack of damage which occurred in that test.

NEAR FIELD PRESSURE GAGES FOR ESKIMO III

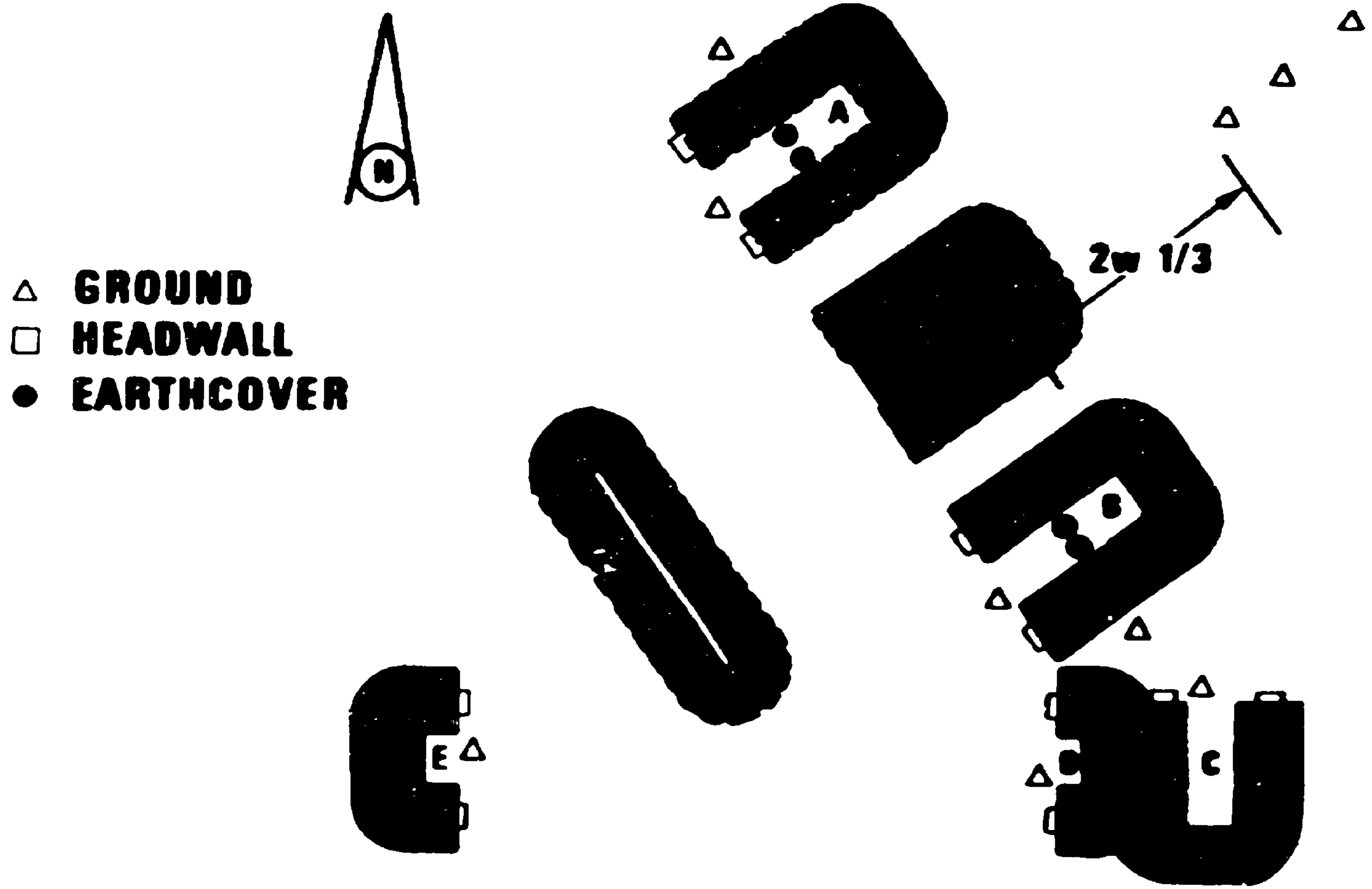


Figure 7

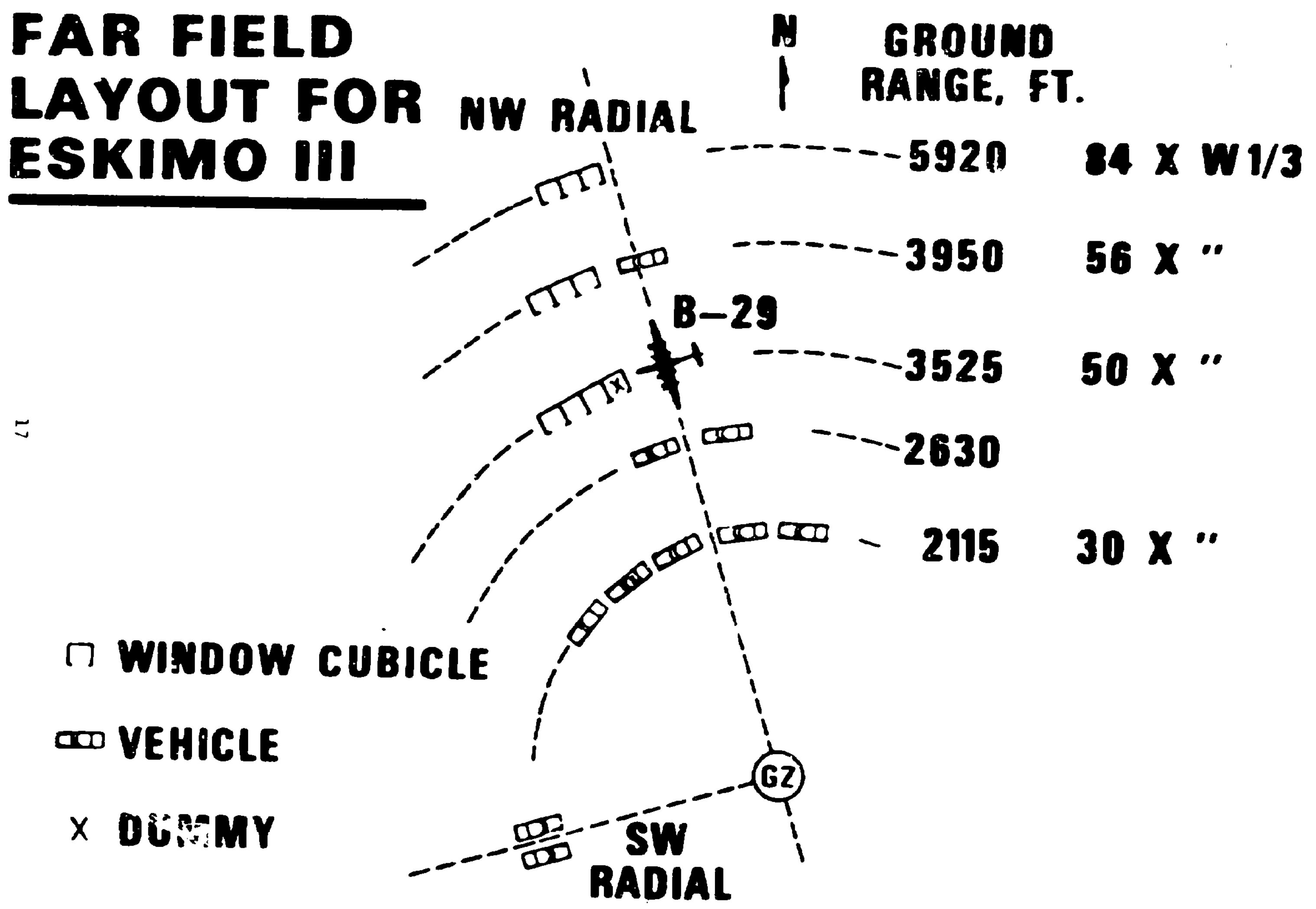

FAR FIELD
LAYOUT FOR
ESKIMO III
NW RADIAL
N
GROUND
RANGE, FT.
5920
84 X W1/3
3950
56 X "
B-29
3525
50 X "
2630
2115
30 X "
WINDOW CUBICLE
VEHICLE
X DUMMY
GZ
SW
RADIAL

Figure 8

Based upon customary cube root scaling predictions, we feel that this additional exposure of the windows and autos should be a valuable adjunct to the test series. The donor charge is large enough to represent the effects of almost any credible accident we might expect, except perhaps a full shipload in a harbor.

This afternoon one of the specialist sessions will be devoted to further discussion of the design of these tests and some of the detailed data derived. We can consider a few questions at this time. These matters will, however, be discussed at greater length in this afternoon's specialist session on this subject.

PRELIMINARY REPORT ON THE MODERNIZATION OF THE NAVAL ORDNANCE PRODUCTION BASE & APPLICATION OF THE HAZARD & RISK ANALYSIS TECHNIQUE

J.O. Gill, NOSC, Crane, Ind.; J. DeGiovanni, Hercules Inc., Cumberland, Md.; J.R. Cerone, A.T. Kearney, Inc., Chicago, Ill.

INTRODUCTION

The Naval Ordnance Systems Command is embarking upon a comprehensive program to modernize and upgrade existing ordnance production facilities, most of them constructed during World War II. The first project to be initiated under this program is the modification of an existing cast explosives plant at Naval Ammunition Depot (NAD), McAlester, Oklahoma, to handle all Department of Defense (DOD) bomb loading and/or other large item cast loading. Ground breaking for this project is scheduled to occur in the near future. Another project in the program is the Western Demilitarization Facility to be constructed at NAD, Hawthorne, Nevada, which will not only demilitarize ammunition, but will also reclaim most of the explosives and certain hardware for reuse and will reclaim scrap metal and other material for resale. Ground breaking for this project is scheduled shortly after the first of the year.

A group of projects, labeled Investment Program - 30, is included in the overall NAVORD modernization program. The Investment Program - 30 was initiated about five years ago by Naval Ammunition Production Engineering Center (NAPEC) and generated hundreds of projects command-wide. These projects thus far have been reduced to 133 with a total estimated cost of $150 million and include offices, pilot lines, containerization, etc.

To round out the definition of the NAVORD modernization program, a contract was awarded last November to A. T. Kearney, Inc., in association with the Ralph M. Parsons Company, Arthur D. Little, Inc., and Hercules Incorporated to perform a comprehensive engineering study of NAVORD production facilities. This paper covers the scope, technical approach, and preliminary results of this study and includes a hazards risk/cost analysis performed on one of the production facilities studies, the 20mm line at NAD, McAlester.

SCOPE

The NAVORD Modernization Study encompasses ten field activities (NAD's Crane, Earle, Hawthorne and McAlester; WPNSTA's Charleston, Concord, Seal Beach and Yorktown; NOS Indian Head; NAVTORSPSTA Keyport), 96 ordnance items ranging from small detonators to large end items, and approximately 55 production facilities associated with these items. With the exception of certain production facilities at Naval Ordnance Station (NOS)/Indian Head that are involved in propellant manufacturing and processing, all production facilities related to the ordnance items being studied are engaged in load and assemble (L&A) operations.

TECHNICAL APPROACH

Problem and Objectives

Most of the production facilities at the ten field activities were built in the early 1940's. With few exceptions, the manufacturing technology and existing equipment represent the state-of-the-art as of 1940 or earlier. The production equipment was operated intensively during World War II, again during the Korean conflict, and recently for the Southeast Asia hostilities. Much of this equipment and a portion of the housing structures, ancillary facilities and utilities have been operated beyond their designed capacities and life expectancy. Some of the production equipment in current use was obtained from deactivated DOD installations and was already badly worn when relocated. Many of the equipment manufacturers no longer exist, and replacement parts for the equipment are not available.

The NAVORD Modernization Study directs a specified level of technical effort at the modernization of selected production facilities and not at the field activities per se. The overall objective of the modernization study is as follows: "To update the production facilities at naval activities under the command of the Naval Ordnance Systems Command in order to achieve a modern production base, capable of responding rapidly and efficiently to fleet munitions requirements."

Guidelines for Modernization Study

To fulfill this objective, several requirements were spelled out, including the following:

(1) Incorporation of the latest, proven state-of-the-art methods, equipment, and applicable industrial practices.

(2) Maintenance of product quality.

(3) Minimizing explosive and personnel hazards in the production facilities.

(4) Abatement and control of environmental pollution.

(5) Reduction of product costs.

(6) Optimum, economical use of existing land and facilities.

(7) Appropriate dispersal of processes and facilities.

(8) Provision of a multiplicity of compatible uses in a given facility.

Allocation and priority implementation models were developed for the study which consider such factors as the following:

(1) Effective production capacity

(2) Pollution abatement

(3) Economic return

(4) Transportation costs

(5) End-item priority

(6) Product quality

(7) Operation costs

(8) Energy requirements

(9) Personnel safety

(10) Industrial protection

(11) Production time availability

(12) Manpower requirements

(13) Community encroachment

(14) Investment costs

Modernization Study Plan

An evaluation of environmental factors for each modified facility and the preparation of Environmental Assessments for selected major projects are included in the study.

The new production plant concepts that are being developed will feature several innovations such as the following:

(1) Computer-controlled operations

(2) Process monitor control

(3) Automatic inspection

(4) Bulk explosive handling

(5) Bulk aluminum handling

(6) Driverless tractor conveying systems

(7) Modular concepts applications which will allow:

   (a) Several ordnance items to be produced on a given line

   (b) Variable capacities

   (c) Reduced injury and damage

(8) Hands-off materials handling systems

An economic analysis will be performed in accordance with Naval Facilities Engineering Command Handbook P-442 and Secretary of the Navy Instruction 7000.14. The primary measure will be the savings to investment ratio. A 20-year economic life for production equipment and buildings is to be considered with a production scenario as follows:

(1) 3 years at peacetime rate

(2) 3 years at wartime rate

(3) 7 years at peacetime rate

(4) 3 years at wartime rate

(5) 4 years at peacetime rate

PRELIMINARY RESULTS OF MODERNIZATION STUDY

Preliminary economic findings to date for all modernization projects being proposed in the study are shown in Table I.

TABLE I

PRELIMINARY ECONOMIC FINDINGS

	Total Investment	Nonmodernization Costs	Modernization Costs	Discounted Savings - 20 Yrs -
All Proposed Projects	$126,450	$73,019*	$53,431	$141,987
*OSHA/PA		8,348		
*Upgrade to Code		41,965		
*Add Capacity		22,706		

(Values in $1,000)

In addition to meeting all OSHA, pollution abatement standards and other codes, the modernization program will greatly enhance the safety environment in the Navy's production plants by reducing the number of personnel required. A preliminary report indicates that the total number of operators that would have to be employed to meet specified production rates during mobilization would be reduced from 4,413 to 2,074, a reduction of 2,339 or 53%. In addition, ten waivers and exemptions out of 13 that apply to existing production facilities studied would be eliminated by implementation of the proposed modernization projects.

Safety features incorporated into these projects include:

(1) Remote controlled operations

(2) Process monitor-control

(3) Use of shielding and barricading

(4) Demand-type explosive materials supply

(5) Dust collection devices

(6) Anti-static devices

A hazard and risk analysis technique that was developed by Hercules Incorporated is being employed in the NAVORD Modernization Study. This technique was extended jointly by A. T. Kearney, Inc., and Hercules during the study to provide for quantifying, in terms of comparative costs, the hazards inherent in the operation of production facilities of competing designs. The remainder of this paper contains an illustration of the application of this technique to the existing and proposed 20mm production facilities at NAD McAlester.

It should be noted that the results of applying this technique have not been fully validated. NAVORD takes the position that these results provide valuable guidance in the design of ordnance production facilities but that the probabilities of incidents and other numerical results may not be wholly accurate in an absolute sense. The technique is much superior to a subjective treatment of conventional sensitivity test results.

HAZARD AND RISK ANALYSIS

Objectives and Advantages

An innovative feature of the modernization study is the quantitative Hazard and Risk Analysis which can be applied to the existing and modernized facilities. The use of this analysis makes it possible to quantify hazards and thus provide the data base for comparative quantitative analysis between the existing and the modernized production facilities. Engineering design criteria can also be provided before design commitment because material response test data, expressed in engineering terms, establishes the maximum critical operating parameters. Other benefits that can be derived from a quantification of hazards involve optimization of safety, cost and productivity through tradeoff of maintenance or modification costs.

Example - 20mm Production Facility

Existing Facility

An example from a portion of the study that has been completed can be considered to convey the methodology and summarize the results. The 20mm production facility has been chosen for presentation because it is a production line that has been completed at this time.

The existing 20mm facilities are located primarily in two buildings at the Naval Ammunition Depot, McAlester, Oklahoma. By today's standards, the facility is antiquated, and it requires high maintenance costs to keep the worn equipment operating. The production of 20mm ammunition on the WW II semi-automatic machinery requires a significant amount of manual labor, resulting in considerable personnel exposure to potential hazards. As shown in Figure 1, several types of projectiles, including the API, HEI, and tracer rounds, are loaded in the existing 20mm projectile loading operations in Building 161. Loaded projectiles are transported to Building 162 (see Figure 2) where cartridge assembly takes place. Other operations performed in this building are powder screening, primer insertion, and pack-out. Much of the material handling occurs in and between Buildings 161 and 162.

Modernized Facility

By contrast, the planned modernized facilities incorporate application of the latest manufacturing technology and state-of-the-art equipment. Improved material flow for all Loading and Assembly operations is located in one building with separate back line-type buildings for bulk smokeless powder screening and supply and for pelleting. Since the production system is continuous flow and "hands-off," except when product design will not permit automation, a total labor reduction of 67% can be achieved. Hazard reduction is achieved through improvements in operating parameters, reduced exposure and lower powder accumulations.

EXISTING

20mm PROJECTILE LOADING BUILDING

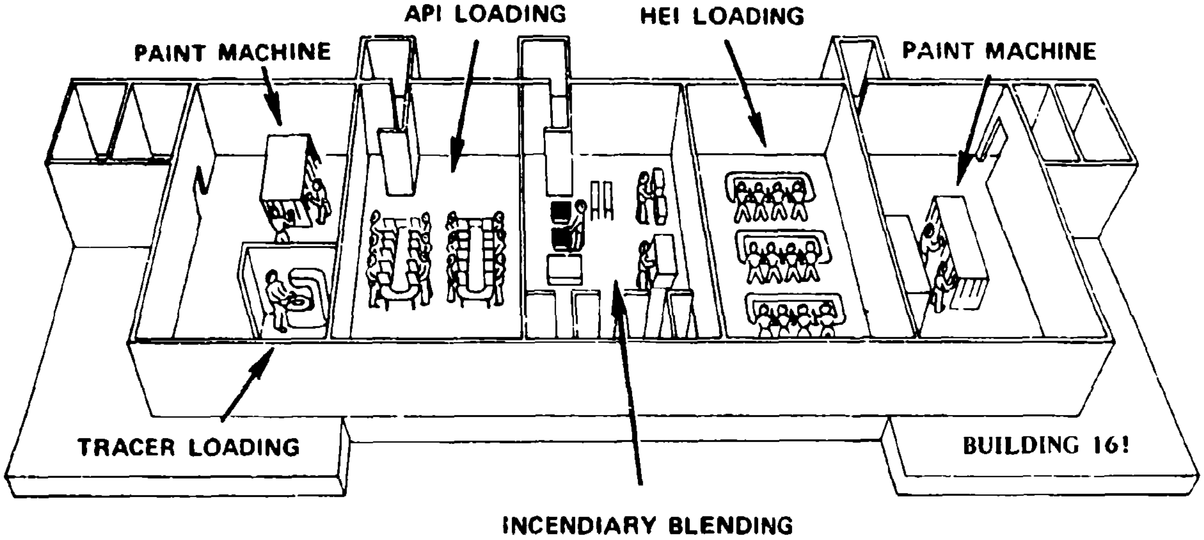


Figure 1

EXiSTING
20mm ASSEMBLY BUILDING

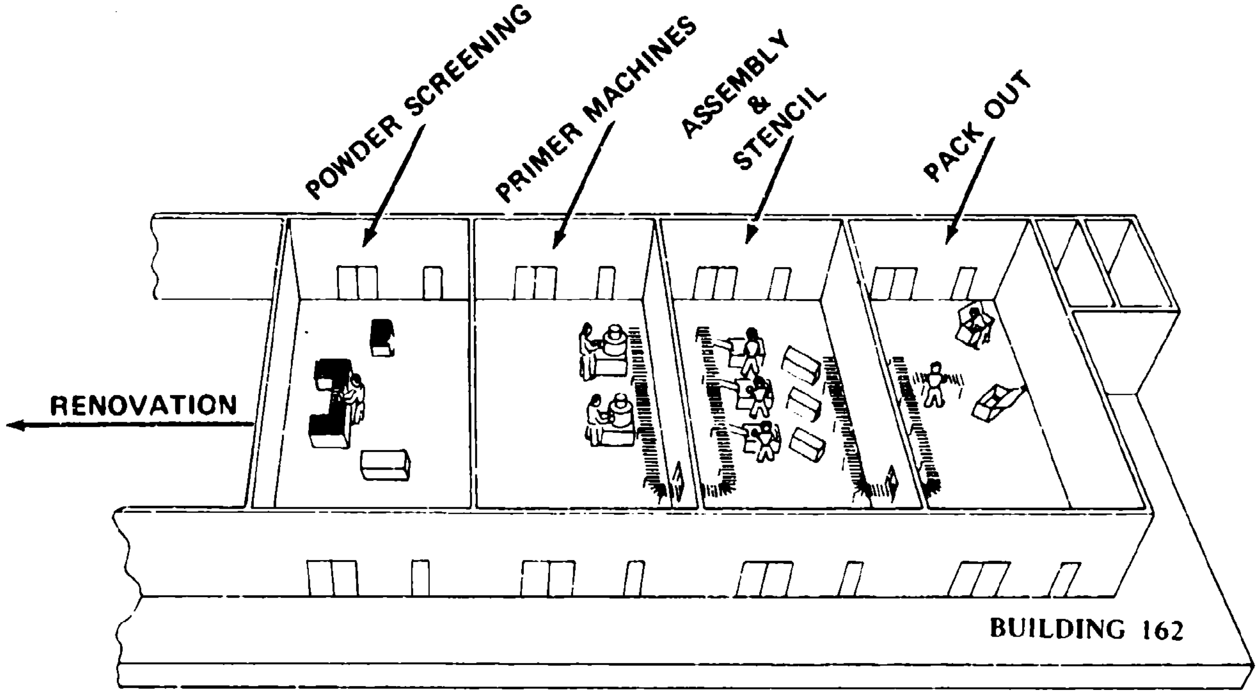


Figure 2

Figure 3 shows the proposed modernized production facility. Inert cartridge and projectile parts from both ends of the building flow toward the center where projectile loading and cartridge assembly take place. Propellant powder is fed into the operation on demand from the supply building. All explosive operations are performed remotely.

Hazards Analysis Methodology

The hazards analysis methodlogy employed for the modernization study can be expressed simply as a quantification of process potentials and explosive material response to provide incident probabilities, a comparative quantitative analysis, and engineering design criteria.

The powder screener conveyor subsystem of the modernized facility (Figure 4) which automatically dumps and screens powder and supplies it to the loading machine, on demand, via roller and belt conveyor, can be employed to illustrate the hazard and risk methodology used for the study. The methodology was applied identically to both the existing and the modernized production design.

Problem Definition

The first step in the progressive type of analysis used was problem definition. In this step, data are collected on a fact sheet (Table II) to identify critical areas in the process where combustibles are present (Column 3, Table II) and where initiation could occur (Column 2, Table II). Potential initiation modes found in the system, such as impact, electrostatic discharge, and friction (Column 4, Table II), are identified. Other mechanisms include thermal particle impingement, free fall, etc.

Engineering Analysis (Determination of Process Potentials and Material Response)

The engineering analysis phase extends the problem definition by measuring or computing process potentials and expressing them in common engineering terms for each of the critical areas identified during the problem definition. The data fact sheet (Column 5, Table II) shows the inclusion of the potentials in engineering terms for each of the critical areas identified during the problem definition.

With the in-process potentials defined, it then becomes possible to establish explosive material response test limits and conditions which simulate the process condition. By determining the material response of the explosive materials in the same engineering terms as the process potential (Column 6 of Table II), the basis for quantifying the hazard of the process is developed.

MODERNIZED
20mm PROJECTILE and CARTRIDGE
LOAD
ASSEMBLY BUILDING

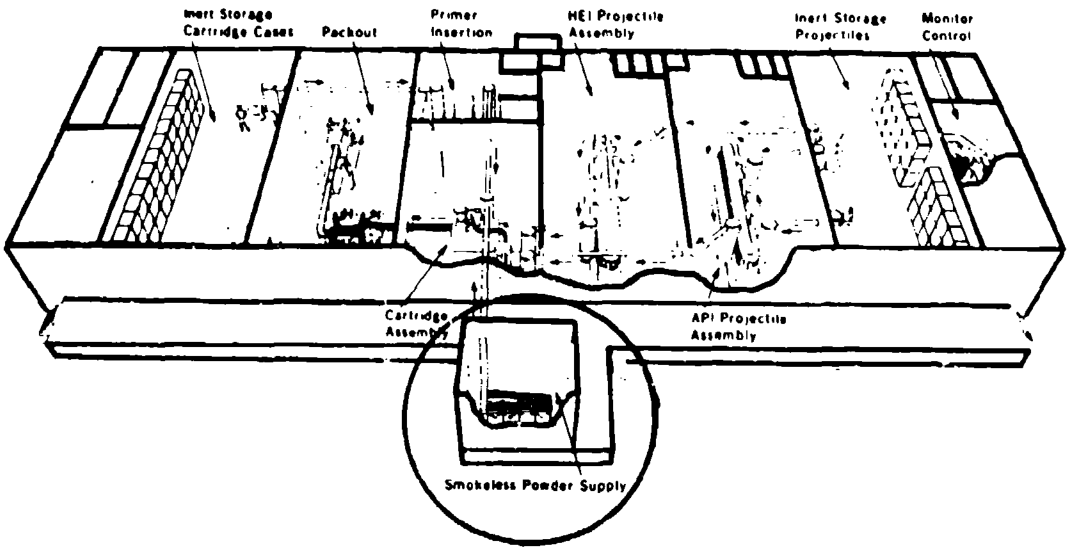


Figure 3

20MM SMOKELESS POWDER

SCREENING SYSTEM

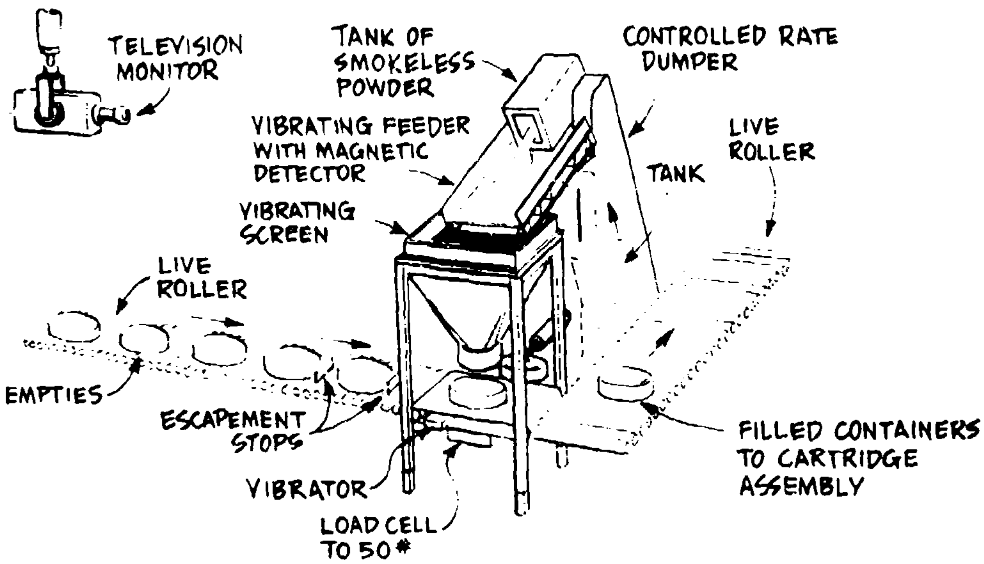


Figure 4

TABLE II

HAZARD EVALUATION SUMMARY

FACT SHEET

(1) STATION NO.	(2) POTENTIAL INITIATION HAZARD	(3) COMBUSTIBLE	(4) INITIATION MODE	(5) PROCESS POTENTIAL	(6) MATERIAL RESPONSE	(7) INITIATION PROBABILITY
15.3	CONTAINER DUMP UNIT	M-10 PROPELLANT	IMPACT – OPERATOR DROPS POWDER CAN LID	11 FT-LB/IN^2	6 FT-LB/IN^2	1.0
15.4	AUTO SCREEN UNIT	M-10 PROPELLANT	ELECTROSTATIC DISCHARGE – DURING POWDER FLOW IF NO GROUNDING	.01 JOULES	.08 JOULES	1×10^{-3}
15.4	EXIT CONVEYOR	M-10 PROPELLANT	FRICTION – CONTAMINATED CONVEYOR BEARINGS	25,000 PSI @ 1 FT/SEC	65,000 PSI @ 1 FT/SEC	1×10^{-4}

The materials tested in the 20mm modernization study were: tetryl, M-10 propellant, two incendiary compositions, and tracer material. By simply comparing the process potential and material response, the safety margin can be found. In practice, however, both of these parameters show a range of values about some normal distribution. Figure 5 shows how the process potential upper limit could overlap the initiation energy lower limit. If this overlapping is found to exist, it must be determined how often this occurs and the probability of initiation. Figure 6 shows a probability or probit plot for M-10 propellant for friction initiation at a velocity of 1 ft/sec. As frictional pressure is increased, so is the probability of initiation. The probability distribution is also illustrated by the upper and lower confidence limits placed on the data. The upper limit process potential for a contaminated roller bearing is 25,000 psi at 1 ft/sec (Column 5, Table II). From the probit plot, it can be seen that the initiation probability at 25,000 psi is 10^{-4}.

Figure 7 illustrates the dependence of friction initiation pressure on the velocity of components sliding against each other. Higher velocities require less pressure for initiation than lower velocities. The velocity-pressure slope varies with the material. In fact, some materials show no slope at all. (Refer to Figure 7 for the slope for tracer material.)

With initiation defined, fire and explosion probabilities can be determined. This fire probability is determined by visually observing initiation results during laboratory testing. Subtle decomposition levels are detected using sensitive gas analyzers, whereas energetic reactions require only the senses of the test operator.

Explosion probabilities are derived from a comparison of bulk container geometry and transition test results for stored materials in hoppers, chutes, shipping containers, etc. Figure 8 shows that there is a relationship between container diameter and height. At small container diameters, the critical height-to-explosion is low while larger container diameters exhibit higher critical heights to explosion.

Use of these data can be demonstrated (Figure 9) by considering what happens in an open container when a flame source is available. If the material height in the container exceeds the critical height, an explosive reaction will result. Material heights below the critical height will result only in burning or in no reaction at all.

Hazards Evaluation

With the definition of initiation established and the probability distribution of the test results clarified, the hazard evaluation can be conducted by comparing the process potentials to the results of material response

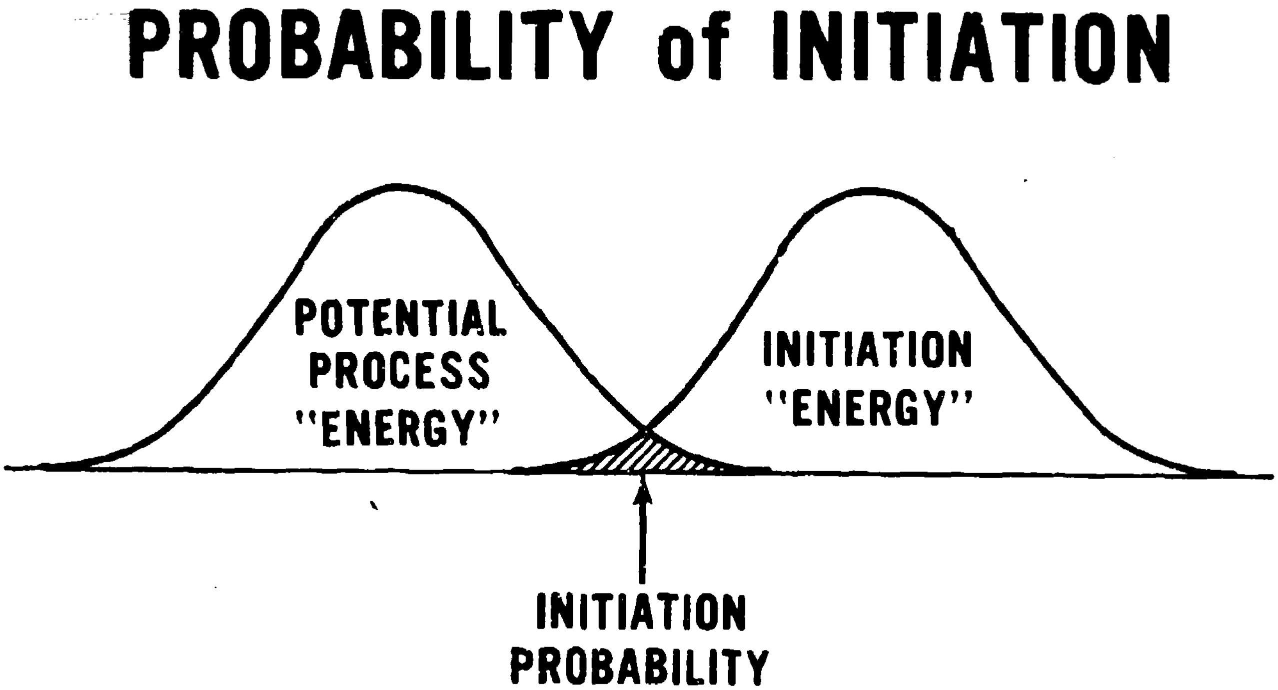

PROBABILITY of INITIATION
POTENTIAL
PROCESS
"ENERGY"
INITIATION
"ENERGY"
INITIATION
PROBABILITY

Figure 5

PROBIT PLOT of M-10 PROPELLANT

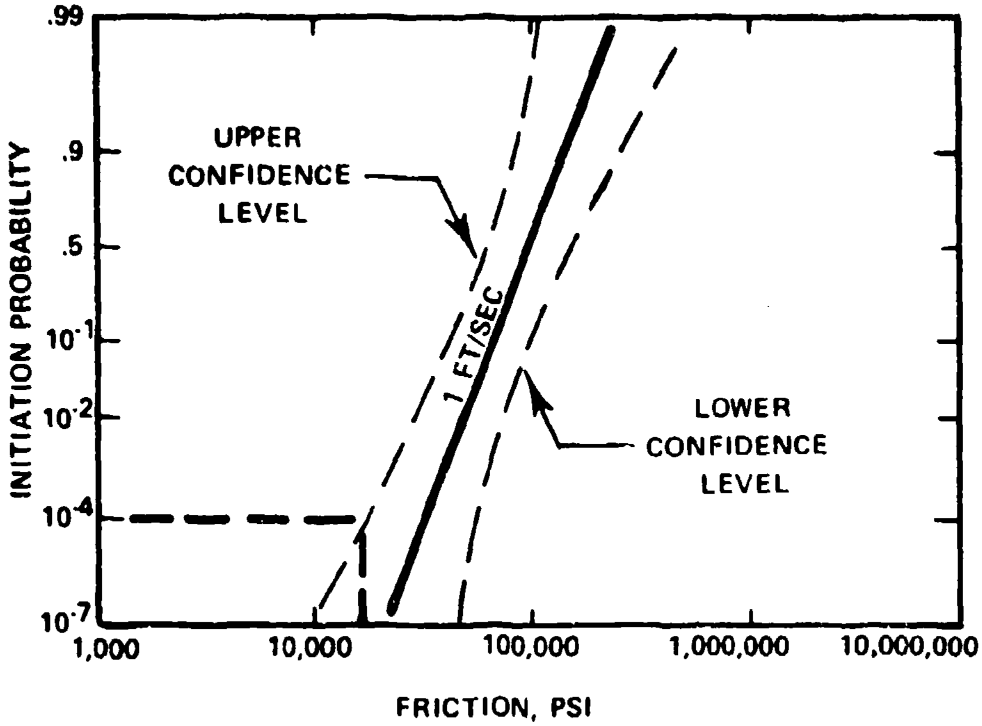


Figure 6

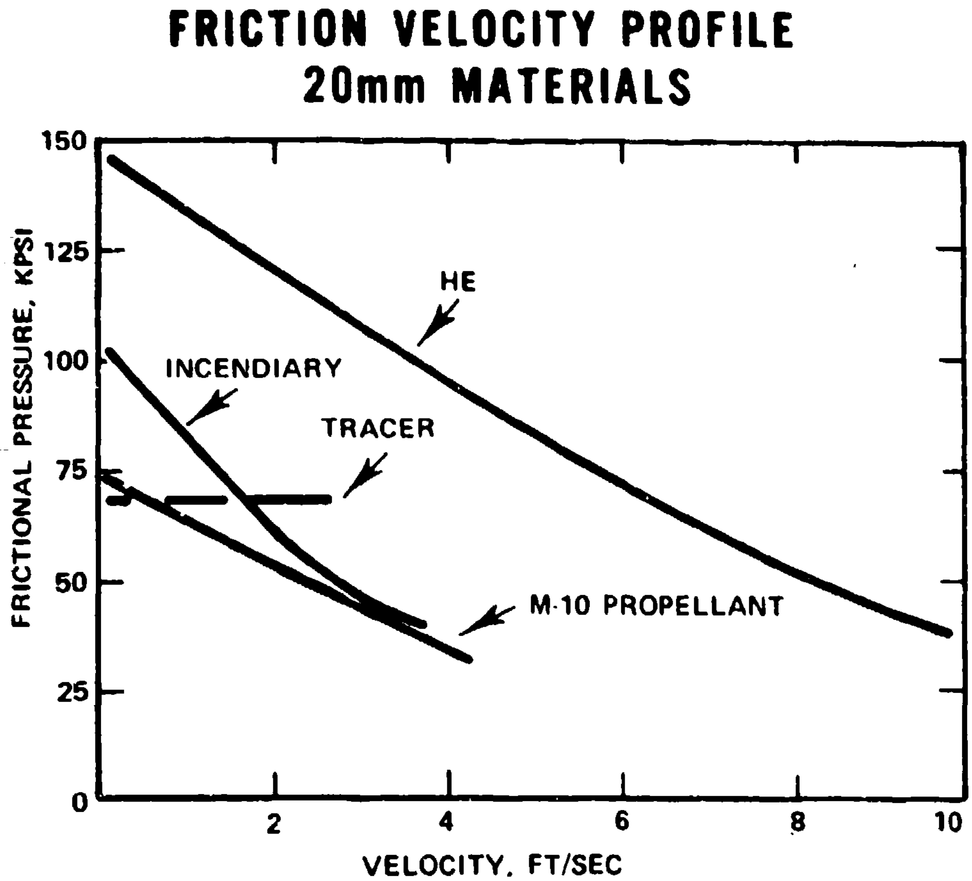

FRICTION VELOCITY PROFILE
20mm MATERIALS
150
125
100
75
50
25
0
FRICTIONAL PRESSURE, KPSI
HE
INCENDIARY
TRACER
M-10 PROPELLANT
2
4
6
8
10
VELOCITY, FT/SEC

Figure 7

TRANSITION BEHAVIOR

CONFINEMENT IS KEY ISSUE –

- CONFINEMENT DIAMETER
- CONFINEMENT HEIGHT (CRITICAL HEIGHT)

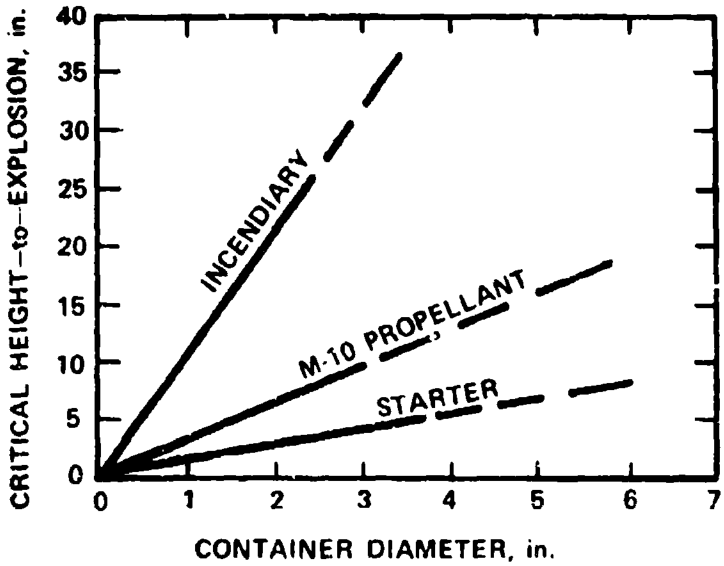


Figure 8

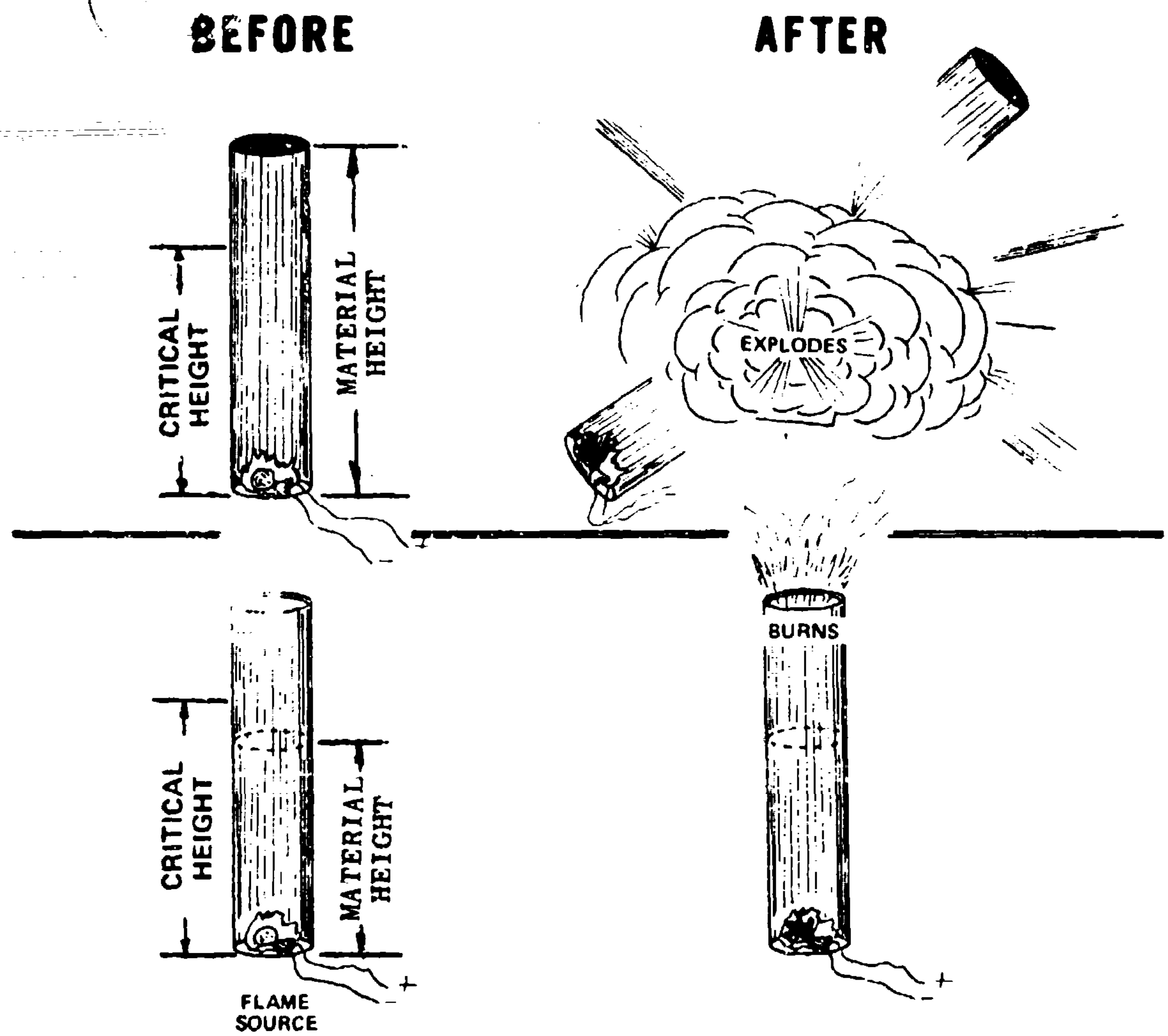

BEFORE
AFTER
CRITICAL HEIGHT
MATERIAL HEIGHT
EXPLODES
CRITICAL HEIGHT
MATERIAL HEIGHT
FLAME SOURCE
BURNS

Figure 9

tests. This comparison is illustrated in Column 7 of Table II. Safety margins can be computed from the ratio of the material response to process potentials. However, as discussed later, determining the initiation probability is more useful to the overall analysis.

To briefly summarize the results of the hazard evaluation of the 20mm facilities, analysis of the existing facilities revealed eight operations and identification of 49 process potentials, with some operations showing high initiation probabilities. These findings agree with historical data which show frequent downtime and some equipment damage. However, with the use of individual work station barricading, serious personnel injury and major equipment losses have not occurred. In contrast, the modernized facilities show improved incident probabilities and personnel exposure. The most significant benefit, however, is the establishment of quantitative design criteria for the modernized facilities.

To consider the overall probability assessment, it must be recognized that initiation probability is only one parameter. To compute the overall incident probability, other factors, such as event probability, contamination probability, fire probability, explosion probability and the number of cycles for each operation, must be considered as shown in Equation (1):

$$TI_p = E_p \times C_p \times I_p \times F_p \times R_p \times \text{Cycles} \qquad (1)$$

where
TI_p = Total incident probability
E_p = Event probability
C_p = Contamination probability
I_p = Initiation probability
F_p = Fire probability
R_p = Explosion probability

Government and industrial data banks for human and component failure rates and laboratory testing provide the necessary inputs for this analysis.

Use of Hazard Evaluation Results

Once the incident probability has been developed, the system cost can be factored in terms of estimated personnel and equipment losses. This methodology for computing the expected loss for both the existing and modernized facilities results in a comparative analysis based on cost. All system costs using this methodology are then summed to yield a total dollar figure for both the existing and modernized facilities so that a comparison can be made. The expected annual loss value for the modernized system ($73,000) shows a significant improvement over that of the existing facilities ($150,000).

An output of the probability analysis is a source engineering design criteria. This output is based on maintaining an incident probability of 10^{-6}

over an operating span of one year and solving the probability equation for the initiation probability (I_p) as shown in Equation (2).

$$I_p = \frac{10^{-6}\text{ (Incident Design Factor)}}{E_n \times C_p \times F_p \times R_p \text{ Cycles}} \tag{2}$$

For example, by ' 'ng in some typical values [Equation (3)]

$$I_p = \frac{10\text{ (Incident Design Factor)}}{0.33 \times 10^{-6} \times 1 \times 1 \times 1 \times 3000 \text{ Cycles}} \tag{3}$$

and solving for I_p [Equation (4)], we can compute an initiation probability of 10^{-2} based on the 10^{-6} design factor.

$$I_p = 0.01 = 10^{-2} \text{ (Initiation Probability)} \tag{4}$$

As shown in the probit plot of Figure 10, for a probability of 10^{-2}, the engineering design value is 41,000 psi at 1 ft/sec. This is essentially the calculation from a probability based on the 10^{-6} design factor used to develop the engineering design criteria. This has been done for all operations and materials, and Table III illustrates a portion of the design criteria that were generated for the 20mm study.

To demonstrate use of these data, a design criterion of 41,000 psi at 0.2 ft/sec was determined for the volumetric feeder for the assembly machine (Figure 11). This criterion is applied to the frictional surface between the rotating drum feeder and drum housing. This, then, is the maximum limit, not to be exceeded, if the 10^{-6} design factor is to be maintained. Other parameters, such as materials of construction and the drum rotational speed, can also be traded off.

Optimization of Safety, Cost, and Productivity

Another use for probability data can · cited. Tradeoff studies can be performed during the detailed design p se to optimize safety, cost, and productivity. These tradeoffs could be based on either maintenance or modification costs as depicted in Figure 12. For example, the expected loss of the system as a function of a clean-up maintenance interval can be computed and the role of production and labor costs can be defined. Figure 12 shows that as the maintenance interval increases (that is, less frequent maintenance), the production and maintenance labor costs decrease because of less frequent downtime. However, the expected losses due to an incident would increase as a result of infrequent cleanup. By combining these curves, an optimization curve as shown in Figure 13 is obtained that isolates the optimum maintenance interval. If the probability at optimum cost does not meet a predetermined design factor, then the graph shows that a lower, more acceptable probability is available at some predictable sacrifice in cost. In this way,

a decision maker is provided with the optimization of risk versus cost so that he is better able to accept his design or to look for other methods of improving risk.

SUMMARY

This preliminary report shows that modernization of the overall Naval Ordnance Production Base can significantly improve overall operating costs, meet OSHA and environmental standards, and provide technical guidance for enhancing the safety of the explosive related operations.

PROBIT PLOT of M-10 PROPELLANT

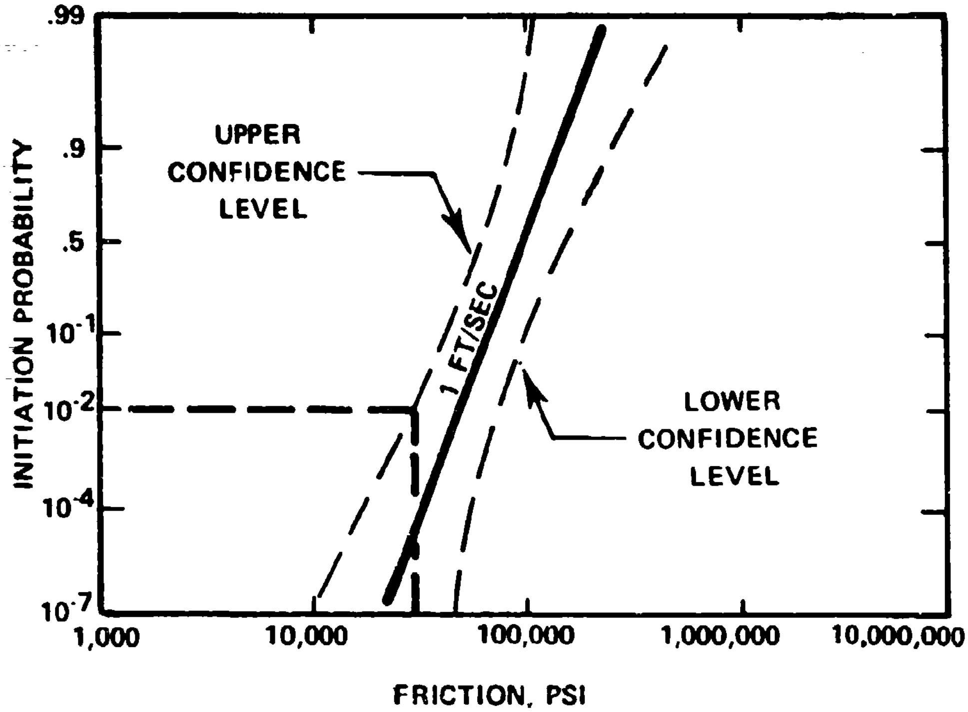


Figure 10

TABLE III

DESIGN CRITERIA for M-10 PROPELLANT

STATION NUMBER	EQUIPMENT SPECIFICATION NUMBER	STATION IDENTIFICATION	INITIATION MODE	MAXIMUM ALLOWABLE POTENTIALS			
				FRICTION	IMPACT	ESD	IMPINGEMENT
6 3 a	8	ASSEMBLY MACHINE	FRICTION AT VOLUMETRIC FEEDER	41K PSI @ 0.2 FT/SEC	-	-	-
6 3 b	26	PROJECTILE MATING AND ASSEMBLY	FRICTION BETWEEN PROJECTILE AND CASE IF CONTAMINATED	40K PSI @ 0.3 FT/SEC			
6 1 a	29	ACCUMULATION CHUTE	FRICTION DUE TO VIBRATION IF CONTAMINATED	36K PSI @ 0.8 FT/SEC			-
15 1 a	40	CONTAINER DUMPER	IMPACT OF 110# POWDER CAN INTO DUMPER	-	3 FT LBS/IN^2		
15 1 b	40	CONTAINER DUMPER	OPERATOR DROPS LID ON POWDER	-	3 FT LBS/IN^2	0.04 JOULES	
15 2 a	42	AUTOSCREEN UNIT	ESD DURING POWDER FLOW	-	-	-	15,300 FT/MIN
15 2 b	42	AUTOSCREEN UNIT	FREE FALL IMPINGEMENT	-	-	-	-
15 2 c	42	AUTOSCREEN UNIT	FRICTION ON SCREEN IF CONTAMINATED	42K PSI @ 1.7 FT/SEC	-	-	-
15 3	41	EXIT CONVEYOR	FRICTION AT ROLLER CONVEYOR IF CONTAMINATED	52K PSI @ 0.45 FT/SEC	-	-	-

DATA APPLICATION

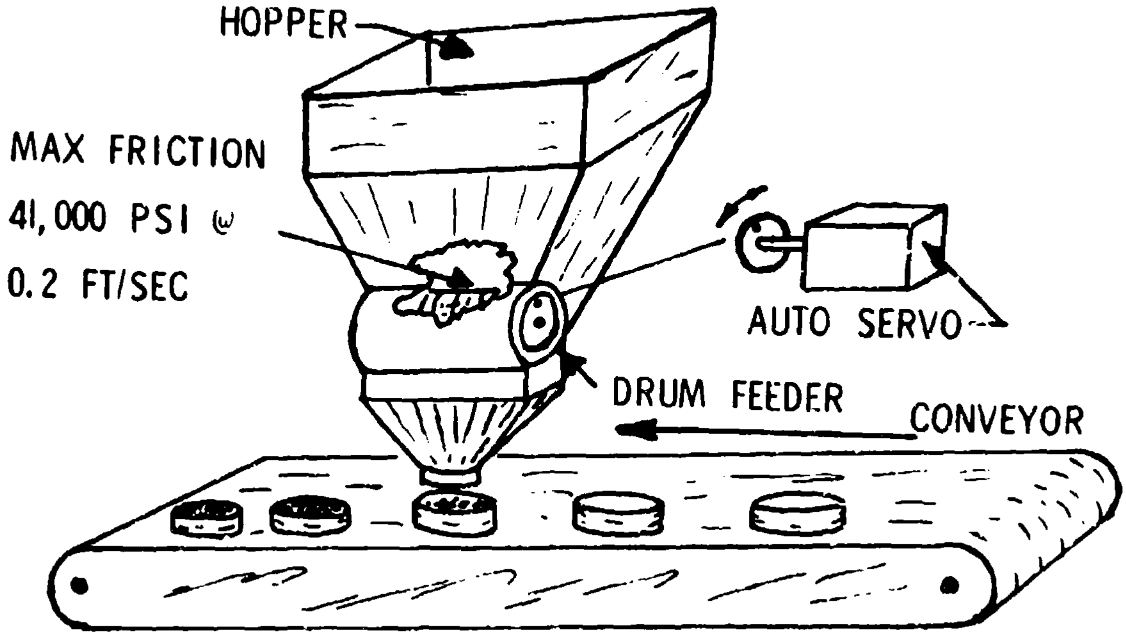


Figure 11

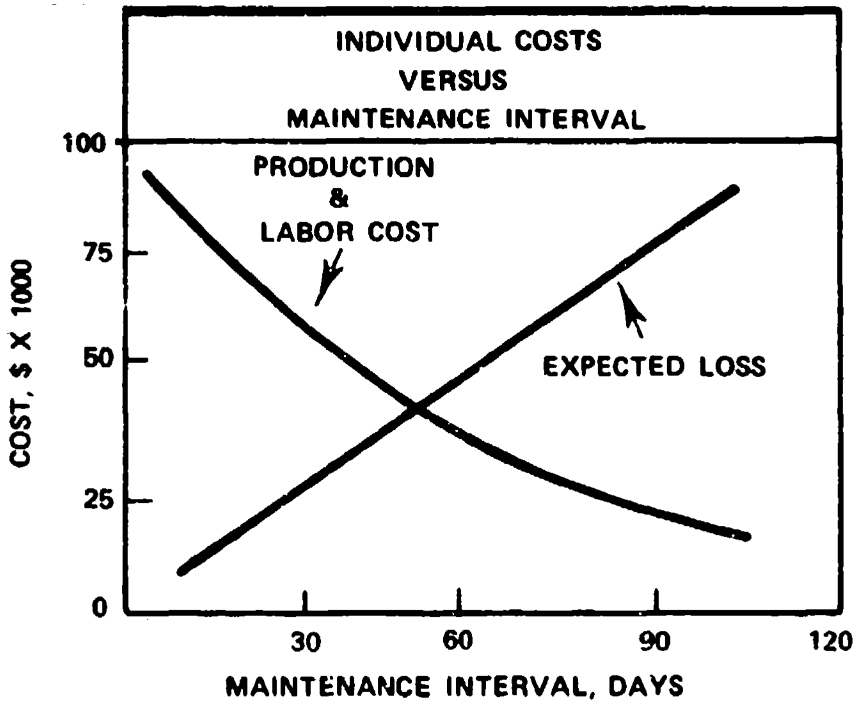

INDIVIDUAL COSTS
VERSUS
MAINTENANCE INTERVAL
PRODUCTION
&
LABOR COST
EXPECTED LOSS
COST, $ X 1000
100
75
50
25
0
30
60
90
120
MAINTENANCE INTERVAL, DAYS

Figure 12

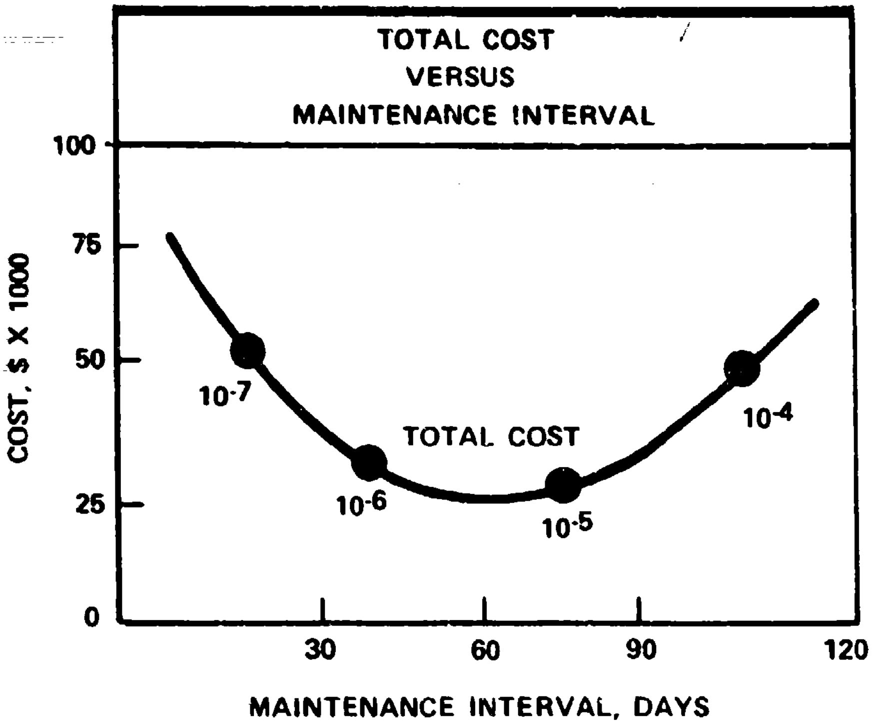

TOTAL COST
VERSUS
MAINTENANCE INTERVAL
100
75
50
25
0
COST, $ X 1000
10-7
10-6
TOTAL COST
10-5
10-4
30
60
90
120
MAINTENANCE INTERVAL, DAYS

Figure 13

MODERNIZATION OF AN AMMUNITION LOADING FACILITY

by

C. R. Goff
Day & Zimmermann, Inc.
Texarkana, Texas

Members of the DOD Explosive Safety Board and guests, this session is for the purpose of discussing Modernization of an Ammunition Loading Facility at Lone Star Army Ammunition Plant, a GOCO plant operated by Day & Zimmermann, Inc., located near Texarkana, Texas. This modernization proposal was initiated some six years ago and was the first approved under the Army's Five Year Modernization Program.

As this was the first program of its kind, there were many obstacles to overcome. Clear-cut guidelines had not been established, and it soon became apparent that our previous method of appointing one Project Engineer to coordinate efforts would not be effective. A Projects Department, Engineering Division, was established, comprised of specialists in Industrial, Safety, and Production Engineering. Subsequently, we have added Technical writers and a Chemical Engineer in the interest of Pollution Control. At present this department assembles and coordinates efforts on some 26 projects, totaling an estimated 185.4 million dollars in value, for the Production Base Support Program.

Not all of these projects are funded, and some are not scheduled for funding until 1981. The correspondence and paper work required for Modernization is somewhat staggering, which leads one to think that Modernization could well afford some streamlining itself. A brief survey of the files on the first modernization project at Lone Star revealed there are 771 pieces of correspondence, totaling in excess of 2,000 sheets of paper, directed to higher authority seeking approvals on everything from site location to pushing the first start button. This does not include the hundreds of drawings, the numerous conferences held at Lone Star, APSA, MUCOM, and Picatinny, the telephone calls, and the teletype messages. Becoming acquainted with your District Corps of Engineers' likes and dislikes, do's and don'ts, is another story I will not indulge in at this time. Briefly,

gentlemen, what I am saying is that Modernization does not come easy, but it can be done. If you are associated with an Army installation and have such ambitions, I strongly recommend you acquire the following regulations and documents for guidance.

1. AR 700-90 - Army Industrial Preparedness Program

2. AR 37-13 - Financial Administration Economic Analysis of Proposed Army Investments

3. AR 385-6 - Safety Requirements for New Construction and Major Modifications

4. MUCOM 385-6 - Safety Requirements for New Construction and Major Modifications

5. MUCOM 11-16 - Army Programs - Economic Analysis of Proposed USAMUCOM Programs

6. MUCOM 11-5 - Army Programs - Production Base Support Programs

7. MUCOM 18-13 - Management Information Systems - Facility Management Information System

8. MUCOM 385-22 - Safety Hazards Analysis

9. AMCR 385-100 - Safety Manual

10. Federal Register, Vol. 37, No. 202 - Occupational Safety and Health Administration (OSHA)

11. APSA 700-9 - Control of Self-Amortizing Equipment Purchases

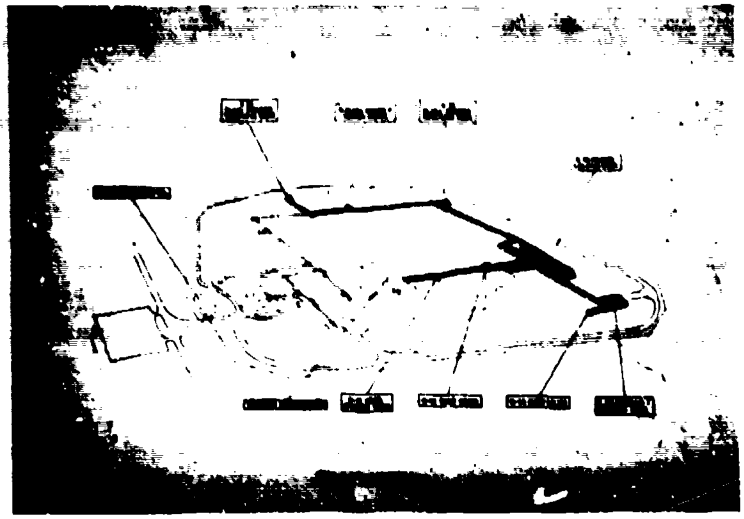
12. APSA 715-12 - Procurement Preparation and Submission of Exhibit P-15, PEMA Provision of Industrial Facilities Justification

13. TM 5-1300 - Structures to Resist the Effects of Accidental Explosions

This first program at Lone Star was for the Modernization of Area R, and at the time we were producing some 2-1/4 million Black Powder Cannon Primers a month, using antiquated equipment, most of which had been in use since World War II. Our prime objective was to eliminate, where possible, personnel exposure to vast quantities of Black Powder being processed in congested work areas. In addition, we had to reduce the cost of production in order that a reasonable amortization of expenditures could be realized. Our Mobilization Schedule at the time was 4-1/4 million Primers a month on a 3-8-5 basis. We set as an objective a facility that could produce this amount on a 2-8-5 basis and amortize within 5 years. This objective could only be met with machines that were yet undesigned to replace the numerous hand operations and with mechanical conveying of materials.

There are numerous commercially available conveyors, and our only real problem was selecting the ones most suitable for our needs. Our Engineering studies projected that we could eliminate 76 employees, the third shift, and reduce man-hour unit cost by .00743. The total cost of the Project was $5,833,638, about 1/2 for building construction and the other 1/2 for equipment, installation, and engineering. Based on the Mobilization Schedule and present unit cost savings, this amount would be amortized in 4.8 years.

An aerial photograph of Area R prior to Modernization.



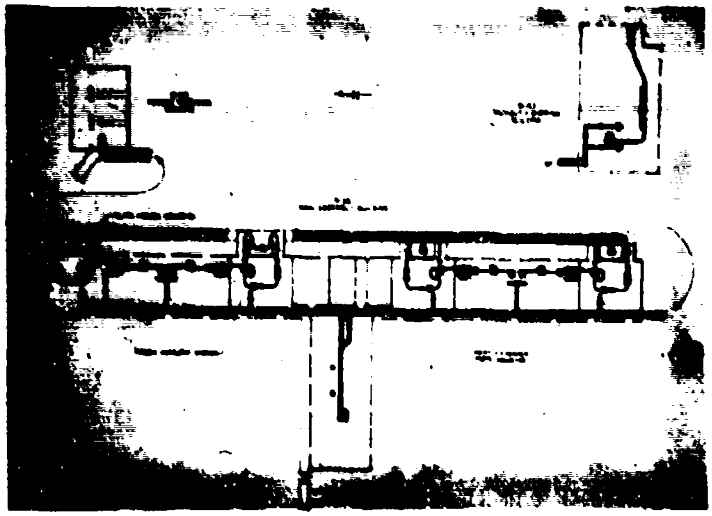
This is an isometric view of both the old section of Area R in white and the new modernized area depicted in black.

Reading from left to right at the top:

1. Change House and Bomb Shelter refurbished and air conditioning added.
2. Bldg. R-32 - Black Powder Receiving Building.
3. Bldg. R-35 - Dry House and Heater House.
4. Bldg. R-36 - Black Powder Receiving Building and Service Magazine.
5. Bldg. R-38 - Primer Loading and Assembly Building.

Reading from left to right on the bottom:

1. Bldg. R-11 - Interior modification.
2. Bldg. R-41 - Primer Head Storage Magazine.
3. Bldg. R-40 - Paint House.
4. Bldg. R-44 - Paint House.
5. Bldg. R-43 - Packout and Shipping Building.



This is a material flow chart in the modernized section depicting the powder receiving building, upper left; load and assembly building and pack and ship building, upper right. The upper lines indicate the Black Powder conveying systems and the lower lines show both the inert material conveyor and the finished production flow to the packout building.

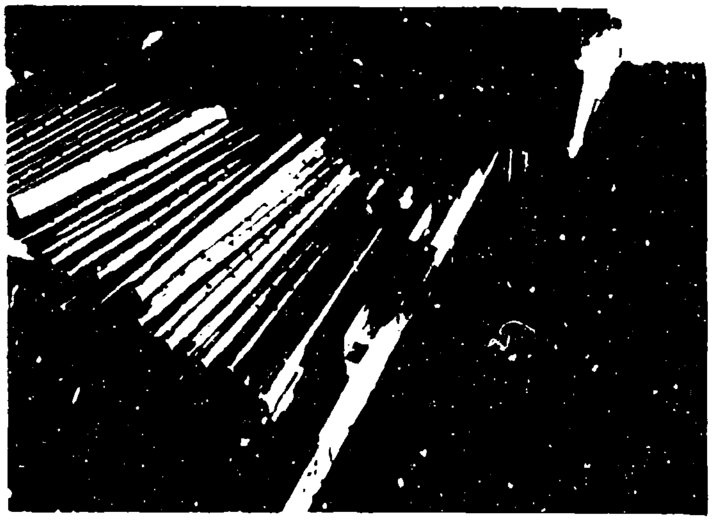
The powder receiving building has two TM 5-1300 walls designed to withstand the effects of 2,000 pounds of Class 7 bulk Black Powder and are 4 feet thick.

The load and assembly building has four powder loading cubicles utilizing 12 inch TM 5-1300 walls which are effective personnel shields for 50 pounds of Black Powder. Also, the bays are separated using the same walls.

The packout and shipping building has one TM 5-1300 wall designed for 3,500 pounds of Class 3 packaged explosives and is 3 feet, 6 inches thick.

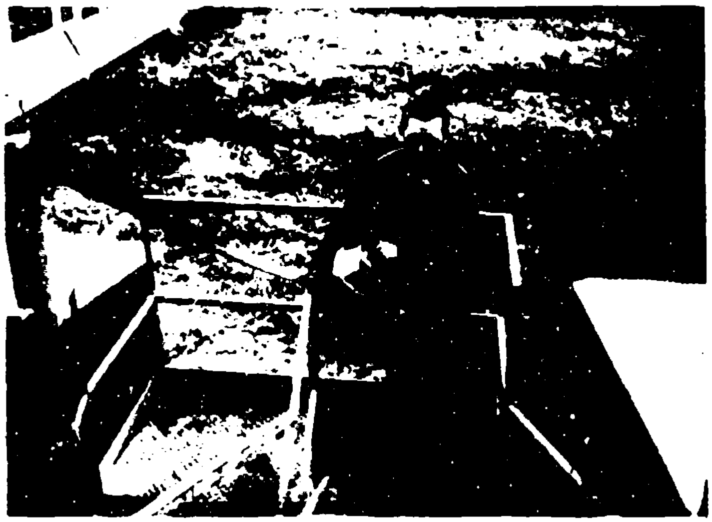
This picture shows the early construction of the powder receiving building. These are the TM 5-1300 walls designed for 2,000 pounds of Class 7 explosives.

The following pictures show a comparison of the old method of primer loading versus the new automated system.



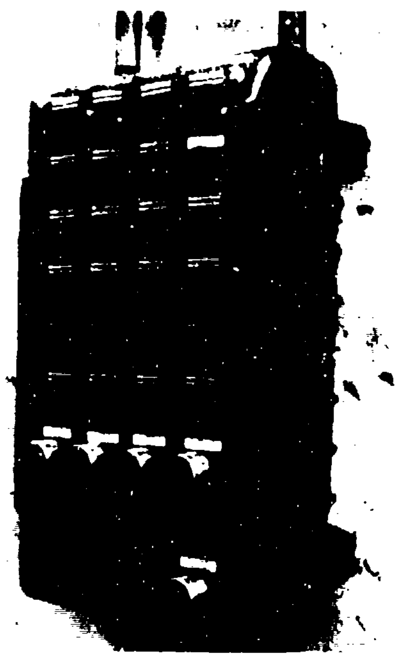
This picture depicts the old hand inspection method for flash holes presence in the primer body. The body is placed over a series of vertical pegs, and a series of horizontal pegs are pushed through the body to be assured of the proper number and location of flash holes. This is a 100% critical inspection requirement. The bodies are subsequently paper lined and lacquered manually.

In the new method, the machine in the center foreground automatically performs the critical inspection for flash holes. It was designed and developed by Day & Zimmermann. The holes are electronically counted, and rejects are automatically ejected through the two holes in the aluminum guard. The machine is adaptable to the various sizes of primers and is capable of inspecting 28,000 bodies per shift. Acceptable bodies are conveyed to and automatically paper foiled, lacquered, and dried in a spiral conveyor in the machines as seen to the right.



This is the old method of transferring powder to the loading hopper. I do not believe further explanation is necessary other than the can contains 25 pounds of powder, and the steps lead to a second floor. The powder was received by hand truck from the magazine.

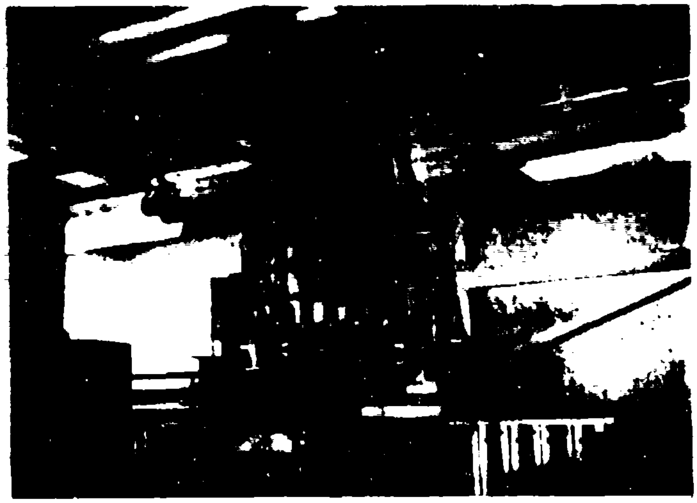
Powder is now received by Cartrac Conveyor from the magazine some 300 feet away. It is automatically and remotely dumped. An ultrasonic device is used to maintain desired powder level in the hopper.



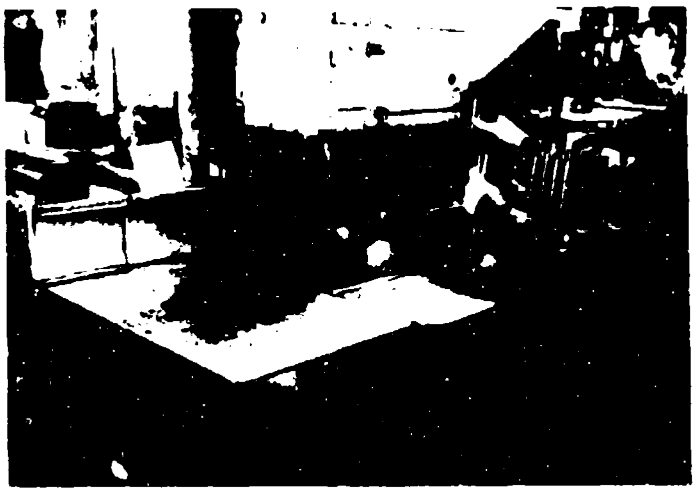
The powder is dispatched by an employee from the service magazine on demand as indicated by the signal and control board shown above. The light indicating low powder level is actuated by the ultrasonic sensing device referenced in the preceding caption.

As shown in the preceding control panel picture, reading from top to bottom, the lights indicate powder presence in hopper, low powder level in hopper, carrier in transit, carrier at dumping station, station in bypass, carrier dispatching controls, key switch resets, system readiness indicators, including conveyor clearance control for returning all carriers to the service magazine, for each of the four individual loading cubicles. This picture was taken during construction; hence, the missing bolts in the cover.

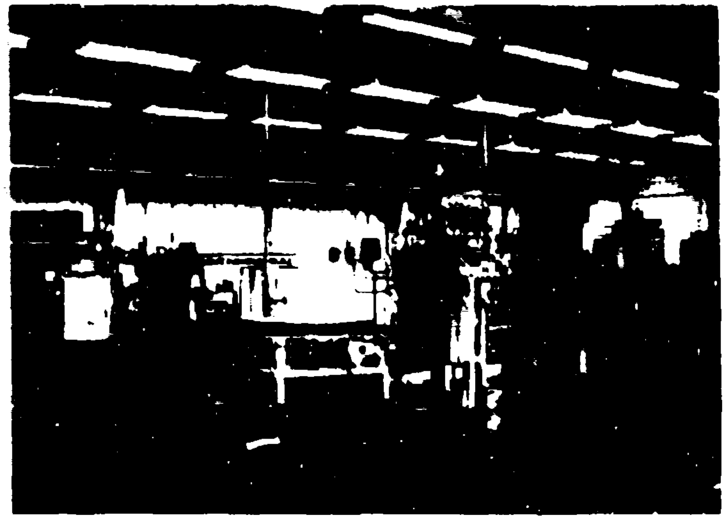
The old manually fed Black Powder volumetric loader is pictured above. After loading, the primers are passed through the wall to the assembly bay as seen on the right. This is the type of operation that automation eliminates completely, precluding the possibility of injury as it is performed remotely in the new system.



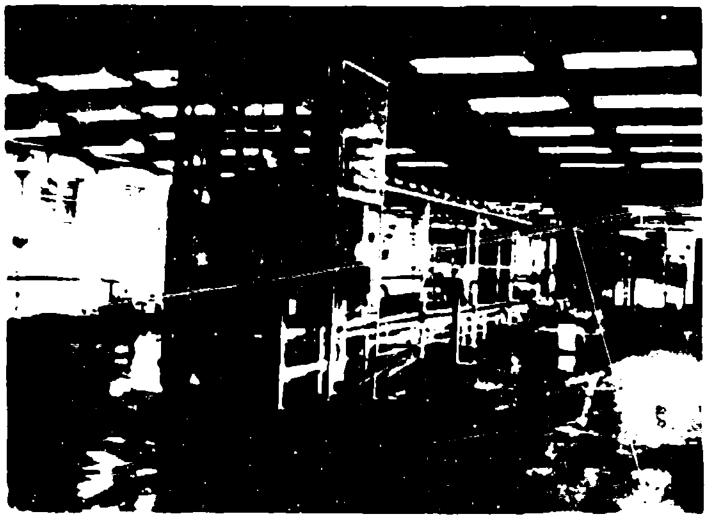
This is the new Day & Zimmermann designed Black Powder Loader. There are ten air operated slide loaders, each of which can be individually adjusted for proper weight. These loaders can be quickly modified to dispense the correct powder weight for all known primers. The loader is located within 12 inch TM walls for 50 pounds of explosives and is completely remote.



This is the old primer head placing, torque, and crimp machine. The parts are hand fed and removed -- another instance of personnel exposure to explosives.

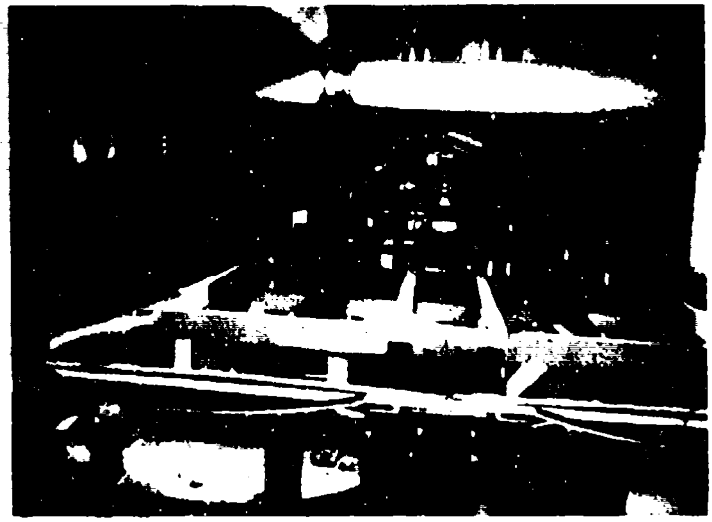


This is an overall view of the new automated assembly system. In addition to assembly, automated inspection stations replace visual and hand methods. Rejects are automatically detected and all stations are shielded. Tests were made for propagation and shielding prior to final design.



This is the new inert material receiving and storage bay. All materials are dispatched on call by carrier. This is the same type Cartrac Conveyor as used in the Black Powder supply system. The empty carriers are returned from the bays and stored on the upper level. They are lowered as needed on the elevator in the foreground for loading in the lower level and are automatically conveyed to the location requesting the supply. A light panel signaling

system similar to the powder supply is used except for manual activation. In the center foreground is another elevator where the loaded carriers are raised to the overhead conveying tracks.



Finished production is transferred from the load and assembly building for the packout and ship building by overhead Cartrac Conveyor. (Picture taken during construction.)

This is the packout bay of the shipping building. Wooden boxes are received by the spiral conveyor on the right.

The shipping bay utilizes an extendable belt conveyor. It is reversible and will extend up to 22 feet into vans. A micro limit switch attached to a bar extending across the end prevents ramming into doors, vans, etc.

I might mention one or two further points of interest. The total cost of the program was, as stated earlier, $5,833,638,00. The original estimate and funding was 6.1 million dollars. This allowed us to return about $300,000 to the Government.

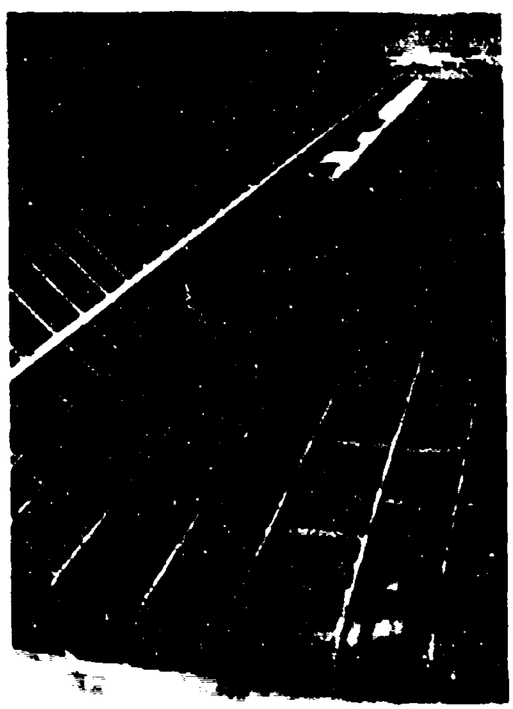
Also, prior to purchasing the four assembly systems, we installed a prototype in one of the old buildings for proving and debugging. This system has been in operation for over a year and has far exceeded our expectations. The original 8-hour production rate was projected for 16,000 primers per shift. We have produced 28,000 in one shift and are presently averaging 21,000 primers per shift on this one machine.

AREA E MODERNIZATION

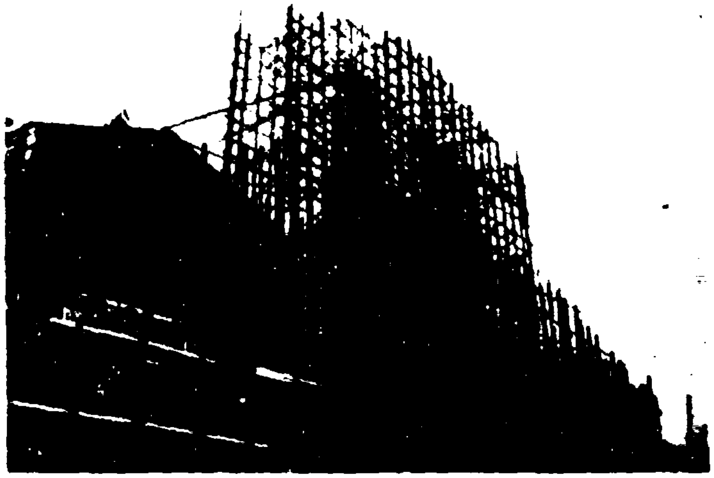
At this time I would like to briefly touch on an additional modernization project. This is the first phase of a 2-phase modernization program in progress at Lone Star. We are presently funded 2.8 million dollars for the automated assembly of 105MM shells in Area E. The melt pour portion of the program is scheduled for funding in Fiscal Year 1975.

In the process of obtaining approvals on Safety Reviews, Hazards Analysis, etc., it was determined that two new TM 5-1300 walls rated for 5,000 pounds of Class 7 explosives would be adequate to modify an existing building for our needs. In order to install these walls it was necessary to remove two old 12 inch reinforced concrete walls. The removal of the walls was accomplished by explosive demolition. The destruction of the two walls was done over a period of two weekends, at times when no production operations were in progress in the area, to avoid personnel exposure. This was, of course, a precuationary measure; however, we found these precautions were really not necessary. In fact, the walls were destroyed, and light bulbs and windows within 20 feet of them were not even cracked. This can be attributed to the method used. The walls were blasted in a series of shots using small amounts of explosives, approximately 1/4 pound, in holes drilled on about 36 inch centers. Heavy steel matting was placed over the walls to confine the fragments.

The following pictures were taken during the construction of the TM walls. These walls are 5 feet, 8 inches, thick, and are sufficient for 5,000 pounds of Class 7 explosives.



The preceding picture is of the steel reinforcement in the wall footing. The large bars are 1-1/4 inches in diameter. The width of the footing is 20 feet. Spot welding is allowed for grounding purposes; otherwise, all joints are wire tied.



This picture was taken at the completion of the third pour. The total weight of steel in one wall is 37 tons.

This picture shows the fifth pour form with other forming removed. Overall height of the wall is 22 feet, 3-3/8 inches. Total weight of concrete is 668 tons.

MODERNIZATION OF AMMUNITION PACKAGING

by

Charles S. Skinner
DESIGN and DEVELOPMENT, Inc.
A Subsidiary of BOOZ, ALLEN & HAMILTON, INC.
8801 East Pleasant Valley Road
Cleveland, Ohio 44131

1. INTRODUCTION

Under sponsorship of Frankford Arsenal and as a part of the Small Caliber Ammunition Modernization Program (SCAMP), our firm is developing a Small Caliber Ammunition (7.62mm) Packaging Submodule System to be installed at the Lake City Army Ammunition Plant, Independence, Missouri. The system is to receive three (3) primary products, as illustrated in Exhibit I, Figures 1, 2, and 3. They are:

- Cartridge, 7.62mm, NATO, Ball M80,
- Cartridge, 7.62mm, NATO, Tracer, M62, and
- Link, Metallic Belt, M13.

Each of these primary products is to be received in a disarrayed bulk configuration and processed at any selected rate between 200 and 1200 parts per minute, excluding rejects. The completed product leaving the Submodule is a palletized unit ready for storage or shipment. There are four pallet pattern configurations which the system is required to complete, three of which are illustrated in Exhibit II. The fourth configuration is with the M548 metal container stacked in two layers.

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EXHIBIT I

7.62mm Linking and Packaging Submodule Primary Products

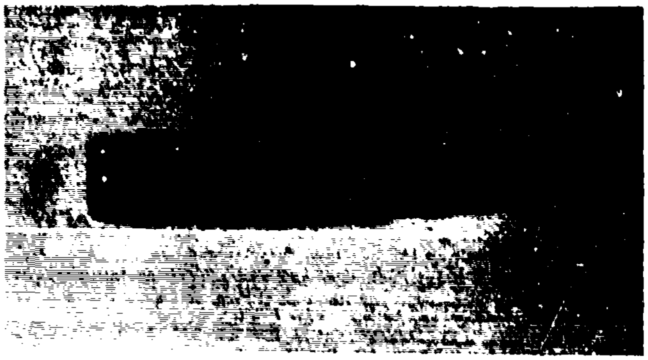


Figure 1 - Cartridge, 7.62mm, NATO, Ball M80

Figure 2 - Cartridge, 7.62mm, NATO, Tracer M62

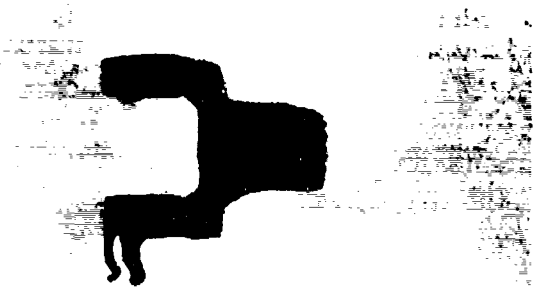


Figure 3 - Link, Metallic Belt M13

EXHIBIT II

7.62mm Linking and Packaging Submodule Completed Pallet Configurations

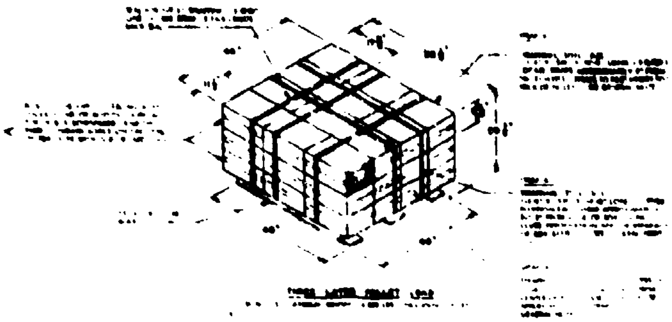


Figure 1 - Wirebound Crates Stacked in Three Layers

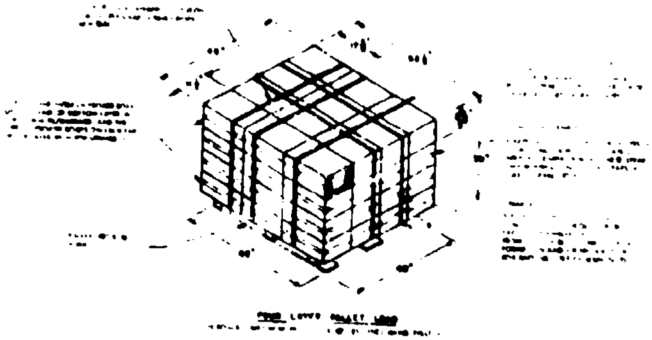


Figure 2 - Wirebound Crates Stacked in Four Layers

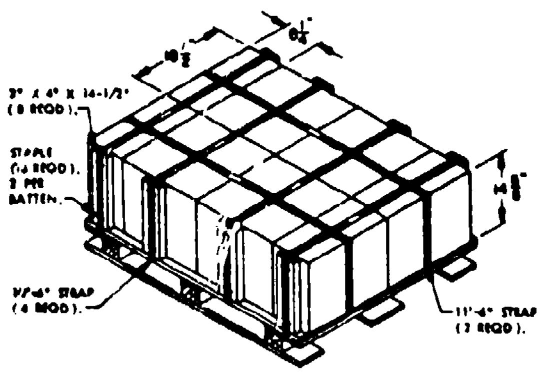


Figure 3 - M548 Metal Containers Stacked In Single Layer With Dunnage

2. SUBSYSTEM FUNCTIONS

The overall Submodule System is comprised of twenty (20) distinct subsystems, as illustrated in Exhibit III. The function of each subsystem is outlined in the following paragraphs.

(1) Link Feed, Orient and Inspect Subsystem

The functions of the link feed, orient and inspect subsystem entail receiving the M13 link in bulk rather than in the current twenty (20) link cartons, as illustrated in Exhibit IV, Figure 1. With an annual procurement of 880 million links, it is anticipated that bulk packaging will result in a one (1) million dollar annual savings to the government. As illustrated in Exhibit IV, Figure 2, links are dumped into a bulk hopper and distributed between eight (8) feeder bowls. The singulated and oriented links are merged onto two (2) link conveyors where they are inspected for hardness, using eddy current instrumentation, and dimension. The dimensional check is to be accomplished by an optical scan to assure:

- Open, unbent loops
- Properly located detent

The defective links are rejected from the subsystem and the acceptable links are transferred into an accumulator, still maintaining orientation, ready for transfer to the Linking Subsystem.

(2) Cartridge Orient and Feed Subsystem

The function of the cartridge orient and feed subsystem entails receipt of ball and tracer cartridges in a disarrayed bulk configuration, orienting the cartridges, and feeding them to the linking machine for intermix and insertion into the links. At the time of publication of this paper, a cartridge feeder design has not been selected, however, several concepts have been developed. There are several cartridge case feeders available, which are primarily the centrifugal type. One is illustrated in Exhibit V, Figure 1, which is capable of feeding at a rate of 600 cases per minute. A new concept developed by us incorporates a Shufflo unit, currently used for feeding cylindrically shaped food products, as illustrated in Exhibit V, Figure 2. The system concept is illustrated in Exhibit VI.

EXHIBIT III

Overall System Layout At Proposed Installation Site

KEY

1. Link Feed, Orient, and Inspect
2. Cartridge Feed and Orient
3. Linking
4. Linked belt inspection
5. 100-round linked belt folding
6. Cartoning
7. Bandoleer insertion
8. M19A1 metal container insertion
9. M19A1 metal container marking and inspection
10. Crating
11. 750-round linked belt folding
12. Corrugated sleeve and separator insertion
13. M548 metal container insertion
14. Crate and M548 metal container marking
15. Inspection and car seal application
16. Crate inversion
17. Palletizing
18. Horizontal strapping
19. Dunnage application
20. Vertical strapping

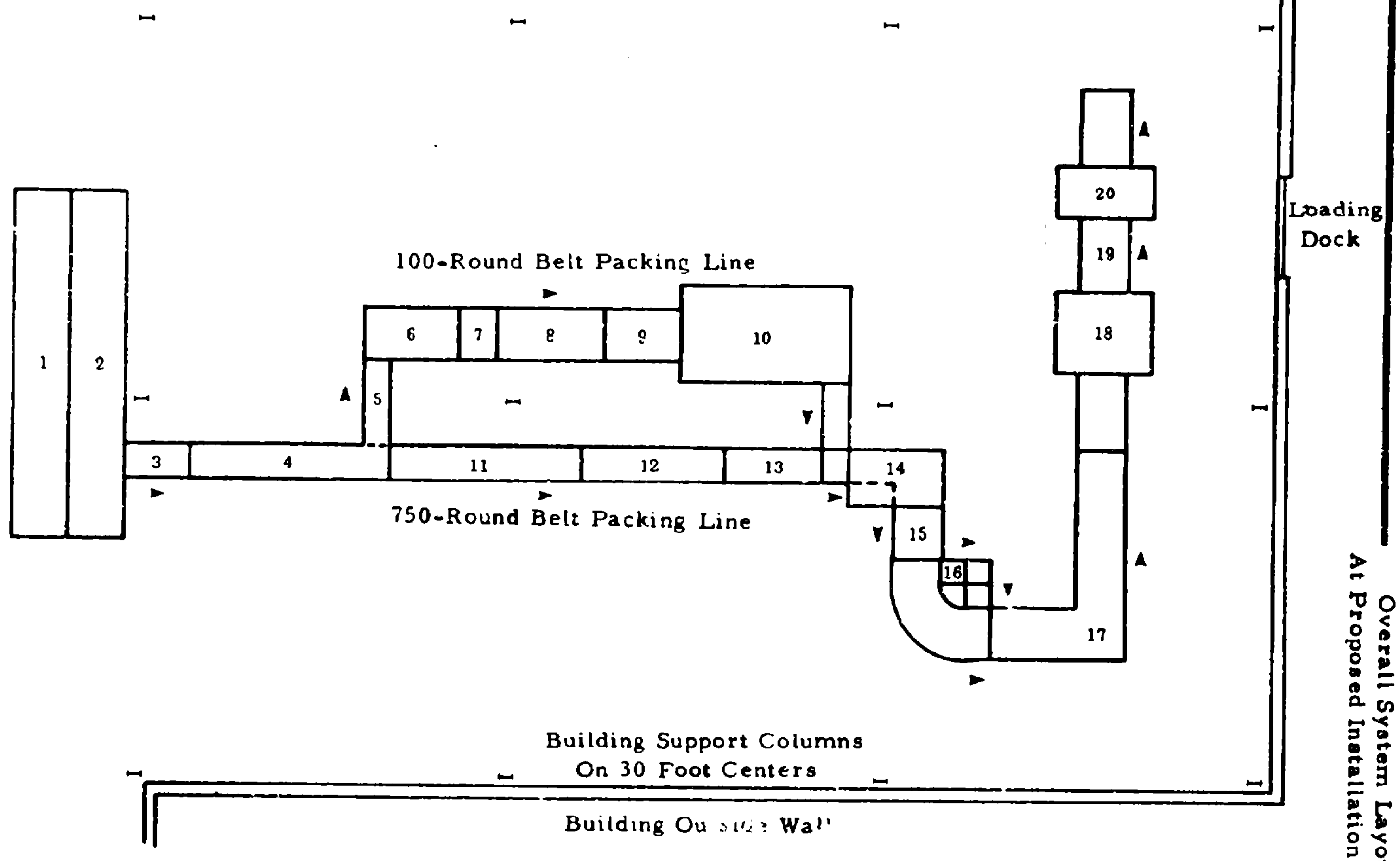


EXHIBIT IV
Link Feed, Orient and
Inspect Subsystem

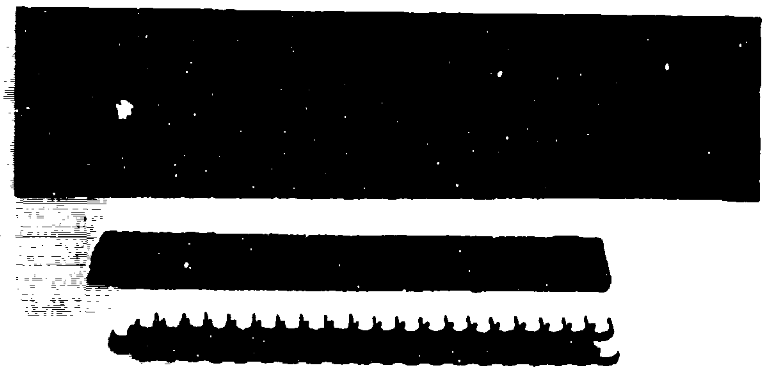


Figure 1 - Current M13 Link Packaging Method - Twenty (20) Links per Carton in Oriented and Assembled Configuration

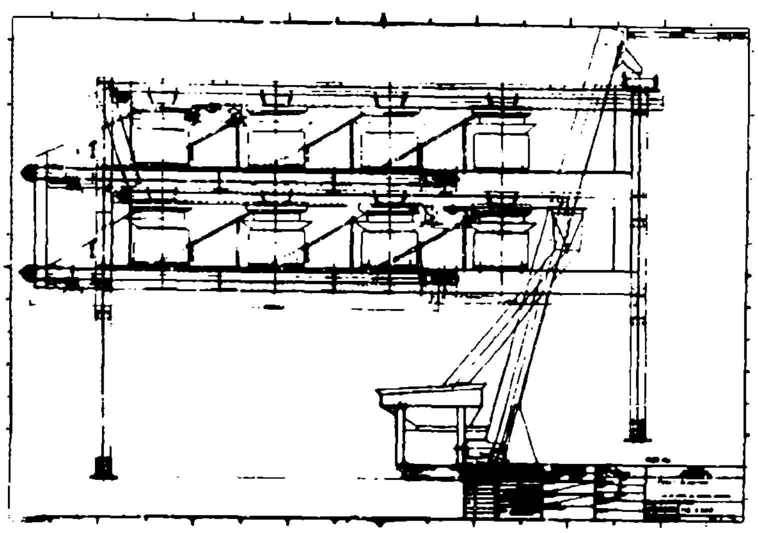


Figure 2 - Elevation View of Link Feed, Orient and Inspect Subsystem

EXHIBIT V
Cartridge Orient and
Feed Subsystem

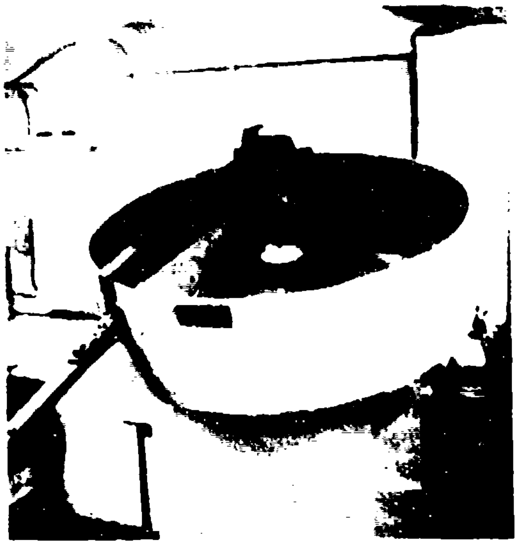


Figure 1 - Currently Available Centrifugal Cartridge Case Feeder

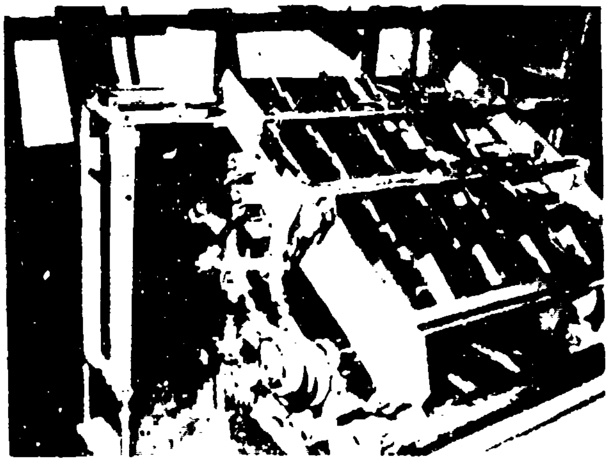
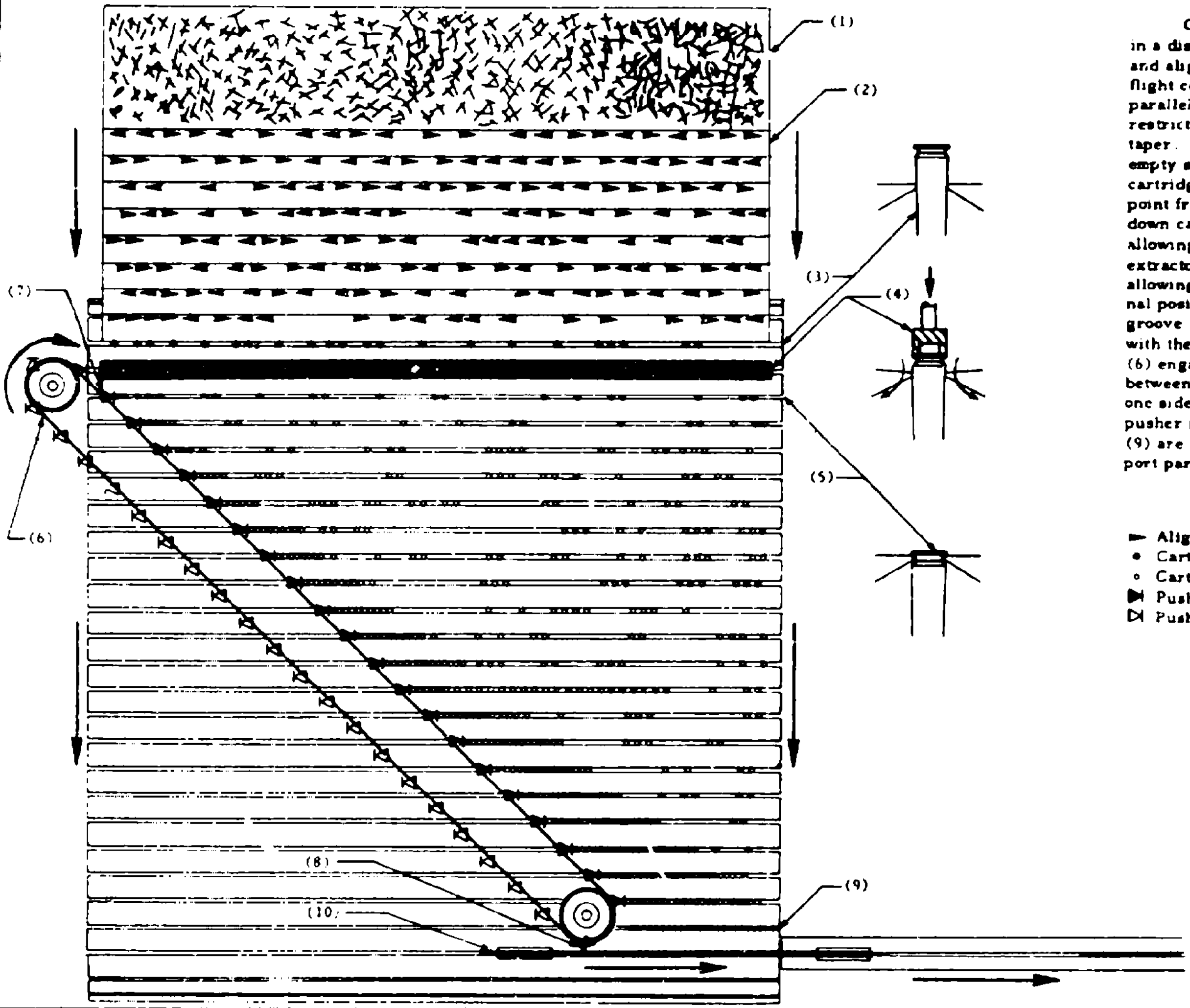


Figure 2 - Shufflo Unit For Feeding Cylindrical Objects

EXHIBIT VI
Cartridge Feeder System Concept



DESCRIPTION OF OPERATION

Cartrid, -s are dumped into the Shufflo hopper (1) in a disarrayed bulk configuration. They are singulated and aligned by the Shufflo (2) and transferred to a flight conveyor (3). The flight conveyor consists of parallel rails which allow the points to fall through but restricts the base end of the cartridge by grasping the taper. As the Shufflo cycles, the conveyor indexes so an empty set of parallel rails are presented to each row of cartridges coming off the Shufflo. At the first index point from the Shufflo, a pusher bar (4) is brought down causing the rotating rails to swing down slightly allowing the cartridges to be pushed through to the extractor groove. The pusher bar is then raised, allowing the rotating rails to spring back to their original position but holding the cartridge by the extractor groove (5). As the flight conveyor continues to index with the Shufflo, a synchronized accumulation conveyor (6) engages the cartridges by extending pushers (7) between the rails, thus accumulating t'e cartridges on one side of the flight conveyor. Before returning, the pusher is extracted (8). The accumulated cartridges (9) are then conveyed by a transfer pusher (10) to transport parallel rails, also engaging the extractor grooves.

Legend

- ▶ Aligned and singulated cartridges
- • Cartridges point down supported by taper
- ◦ Cartridges point down supported by extractor groove
- ▶| Pusher extended between rails
- ▷| Pusher retracted

(3) Cartridge Intermix and Linking Subsystem

Ball and tracer cartridges are intermixed in two distinct ratios:

4: 1 Ball-to-Tracer for 100-round belt functional packs

9: 1 Ball-to-Tracer for 750-round belts

A demonstration "star wheel" model for accomplishing the 4: 1 ratio is illustrated in Exhibit VII, Figure 1. It is capable of feeding four (4) cartridges from an infeed chute and leaving a void for insertion of the tracer by a similar wheel. The ball cartridges are transferred to a pocketed conveyor from the "star wheel", leaving every fifth pocket empty for insertion of a tracer. The completely filled and intermixed conveyor ready for linking is illustrated in Exhibit VII, Figure 2. Links are fed to the same pocketed conveyor, adjacent to the intermixed cartridges, from the accumulator of the link feed, orient and inspect subsystem. The links are fed in the nested, or assembled configuration, as illustrated in Exhibit VIII. The cartridges are then pushed axially into the assembled links, forming a continuous belt. This entire operation is accomplished on a continuous basis. The intermix "star wheels" can be interchanged to accomplish both the 4: 1 and 9: 1 ratios. The continuous belt is subsequently conveyed to the linked belt inspection and separation subsystem.

(4) Linked Belt Inspection and Separation Subsystem

The three (3) subsystems previously discussed are being developed by our firm at our facility in Cleveland. The linked belt inspection and separation subsystem is being developed under a subcontract with Battelle Memorial Institute. The subsystem, as illustrated in Exhibit IX, receives the continuous belt from the cartridge intermix and cartoning subsystem and performs the following inspections:

- Inspects for proper depth of insertion of the cartridge with the linked belt.

- Performs a twenty-five (25) pound pull test to test for soft or malformed links. Should the belt break under a twenty-five (25) pound pull, the system stops.

EXHIBIT VII
Ball and Tracer Cartridge
Intermixing

Figure 1 - "Star Wheel" Demonstration Model For Feeding Ball Cartridges In Groups of Four (4) Leaving A Void For Tracer Insertion

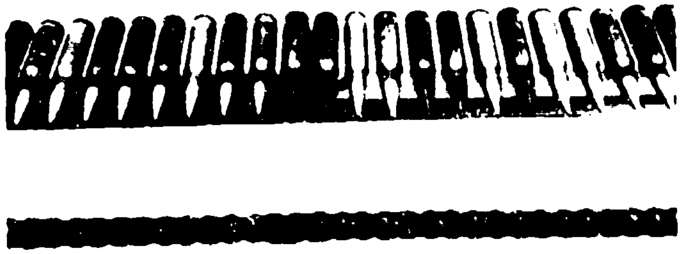


Figure 2 - Completely Filled Pocketed Conveyor With Intermixed Cartridges For Linking

EXHIBIT VIII
Linking Operation

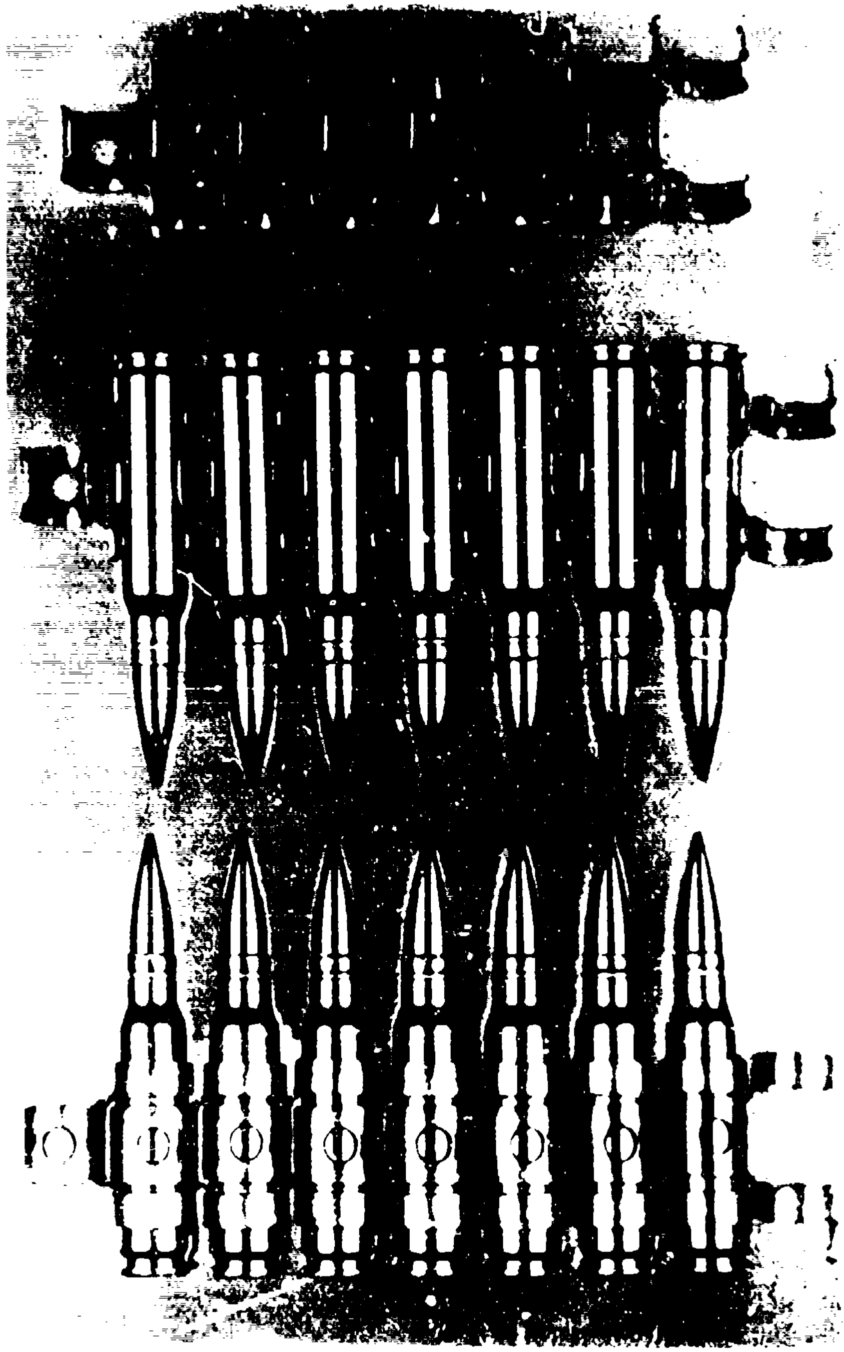
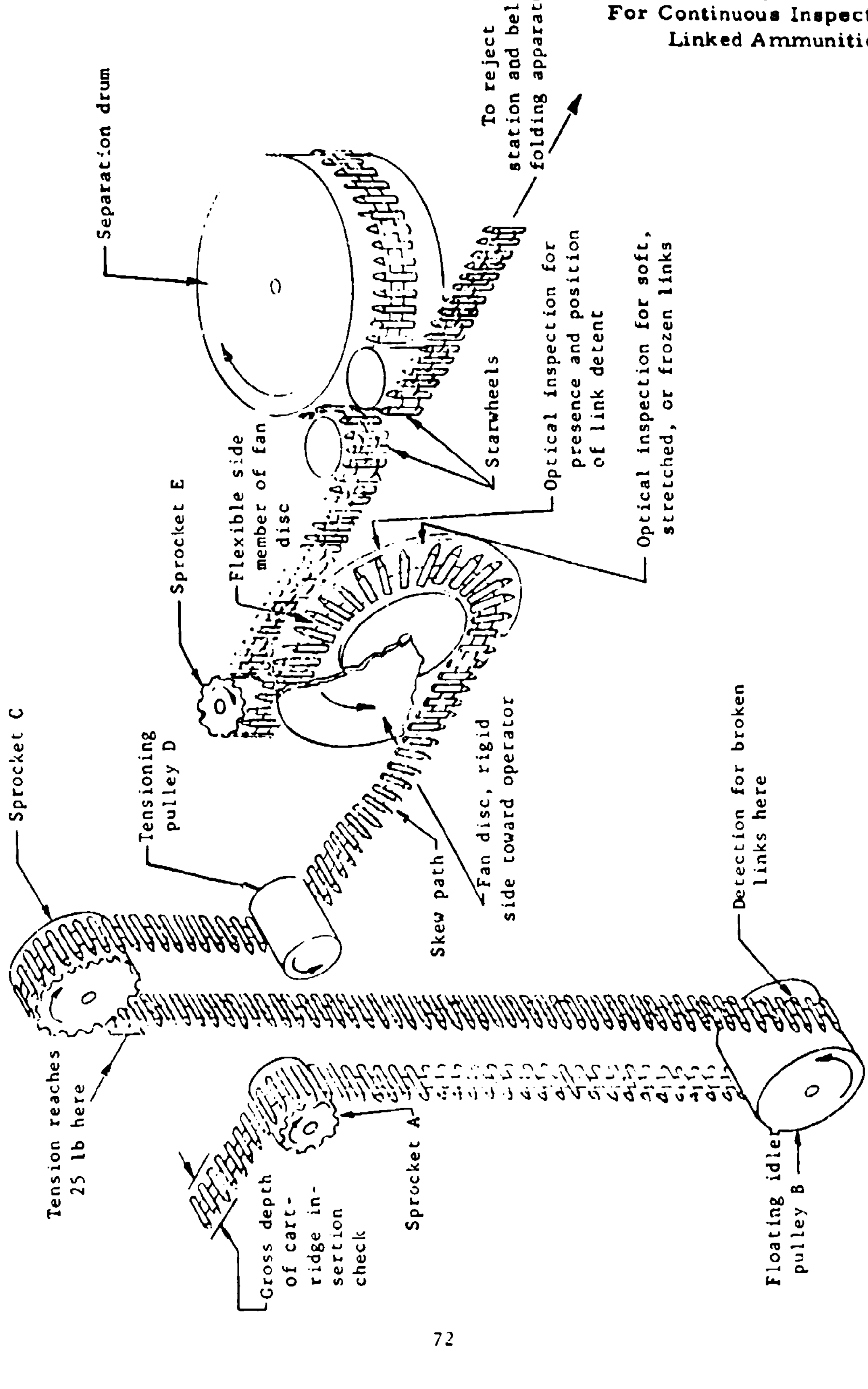


EXHIBIT IX
Schematic Diagram Of Concept For Continuous Inspection Of Linked Ammunition



Optical inspection for soft, stretched, or frozen links, as illustrated in Exhibits X and XI. Frozen links are those with a tight center loop which do not allow the belt to freely flex.

Optical inspection presence and position of link detent.

The continuous belt is then separated into discrete lengths of either 100 or 750 rounds, depending upon their corresponding ball-to-tracer intermix ratios. Should any of the inspections yield a faulty link-to-cartridge assembly, the entire discrete belt is rejected for rework, however, the type of the defect shall be accounted for and the location on the belt shall be marked. These concepts are currently under test using experimental apparatus, as illustrated in Exhibit XII. Subsequent to belt separation, the Submodule line splits into two (2) packaging lines. One (1) for the 100-round belt, and one (1) for the 750-round belt.

(5) <u>100-Round Belt Folding Subsystem</u>

This subsystem is also being developed under the same subcontract by Battelle, and is designed as a part of the previous subsystem, as illustrated in Exhibit XIII. The approach to 100-round belt folding incorporates the folding bar concept, as illustrated in Exhibit XIV. This entails placing the straightened bar over the bullet ends of a straight belt, folding the bar at the articulated joints, and thus the belt in the proper manner, as illustrated in Exhibit XV, Figure 1.

(6) <u>Cartoning Subsystem</u>

The 100-round folded belt shall be transferred to the cartoning subsystem and inserted into a carton, as illustrated in Exhibit XV, Figure 2. This subsystem shall be an off-the-shelf, intermittent motion, horizontal-transfer type cartoning machine, as illustrated in Exhibit XVI.

(7) <u>Bandoleer Insertion Subsystem</u>

The completed carton is subsequently inserted into a M4 bandoleer and the straps wrapped around the functional pack for insertion into the M19A1 metal container, as illustrated in Exhibit XVII, Figure 1.

EXHIBIT X
Concept For Inspecting Ammunition Belts For Tight Or Loose Links

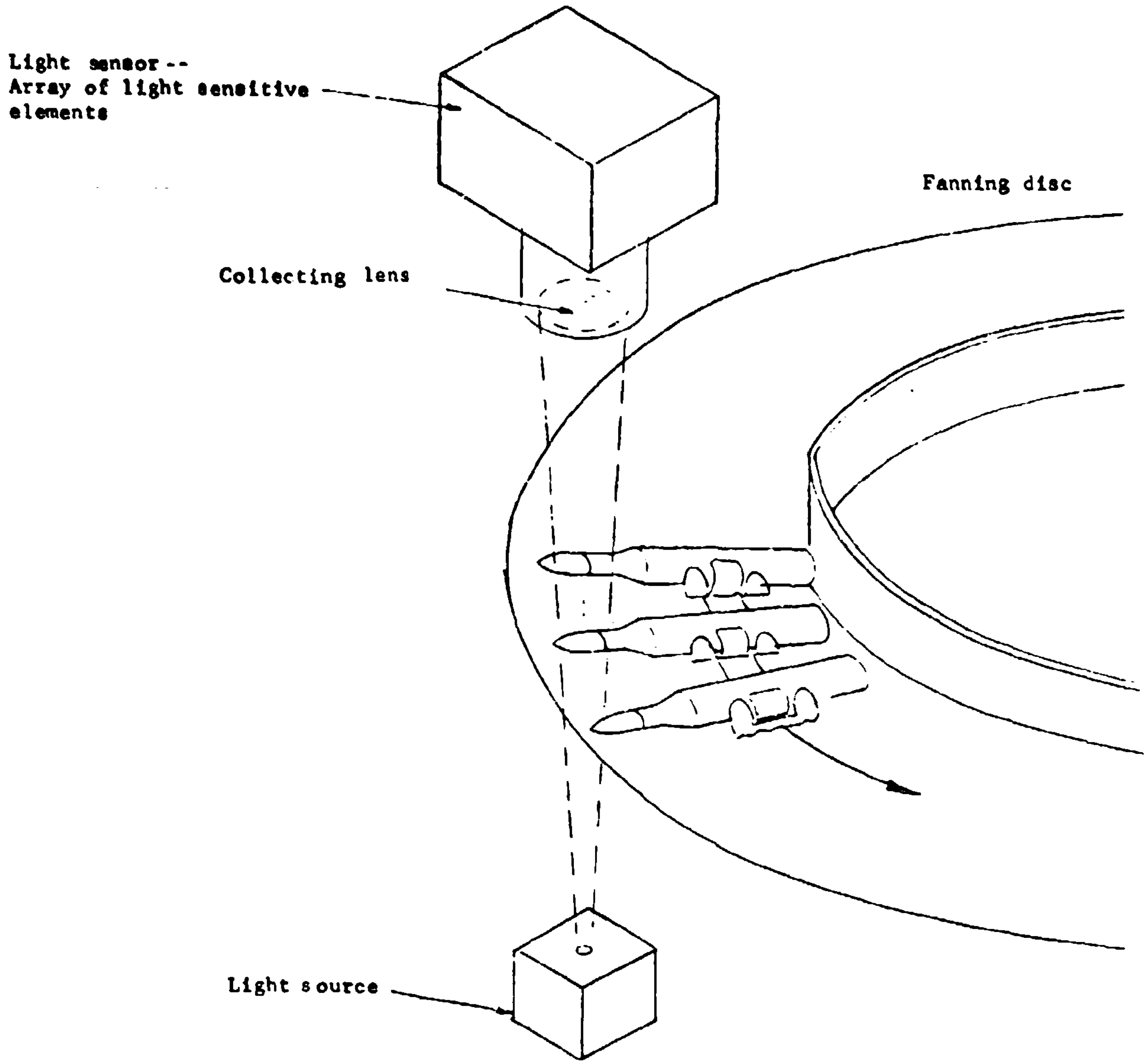


EXHIBIT XI
Belt Arranged In [illegible]
Configuration F[illegible]
Optical Inspecti[illegible]

S - Normal spacing

S_1 - Frozen link spacing

S_2 - Loose or soft link spacing

N - Link de[illegible]t spacing

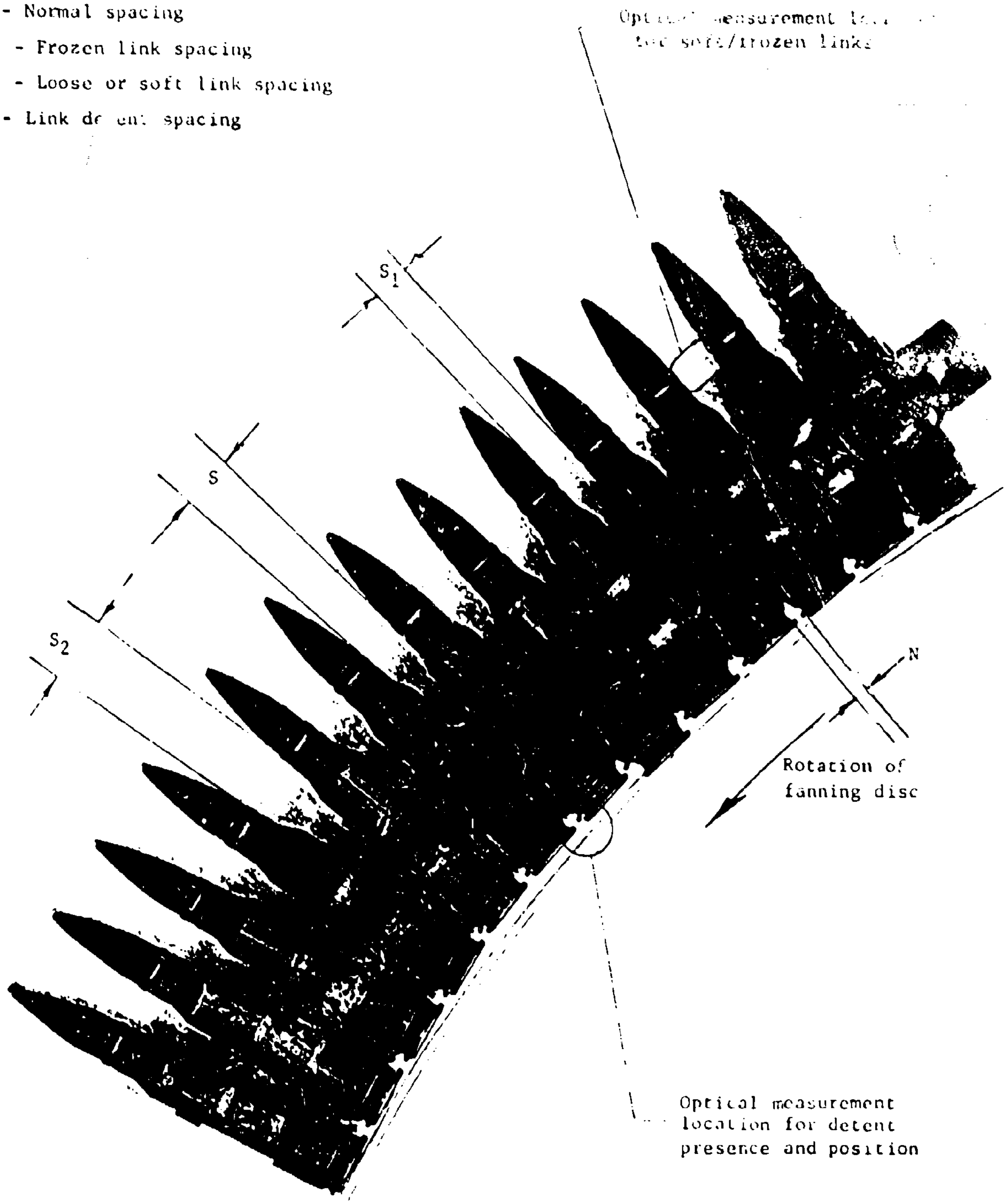


EXHIBIT XII
Continuous Linked Belt Inspection
And Separation Test Apparatus

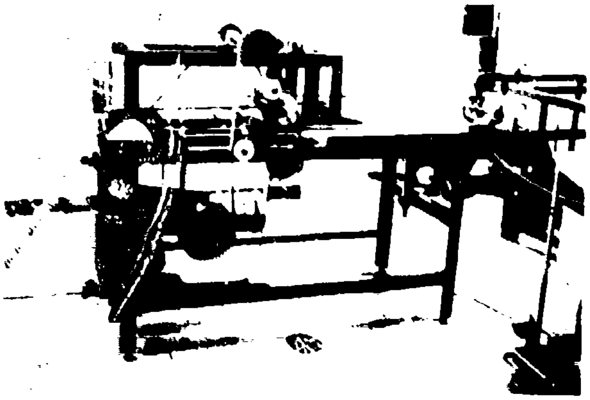


Figure 1 - Continuous Linked Belt Inspection Test Apparatus

Figure 2 - Optical Inspection Disc Using Diode Array Inspection Camera

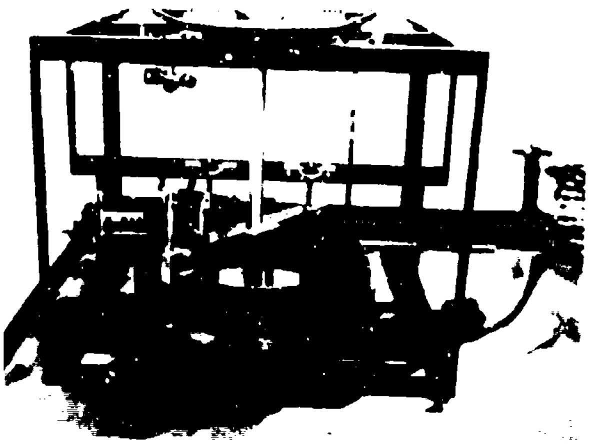


Figure 3 - Belt Separation Test Apparatus

EXHIBIT XIII

Concept For Continuous Inspection Of Linked Ammunition Belts And For Folding 100-Round Belts

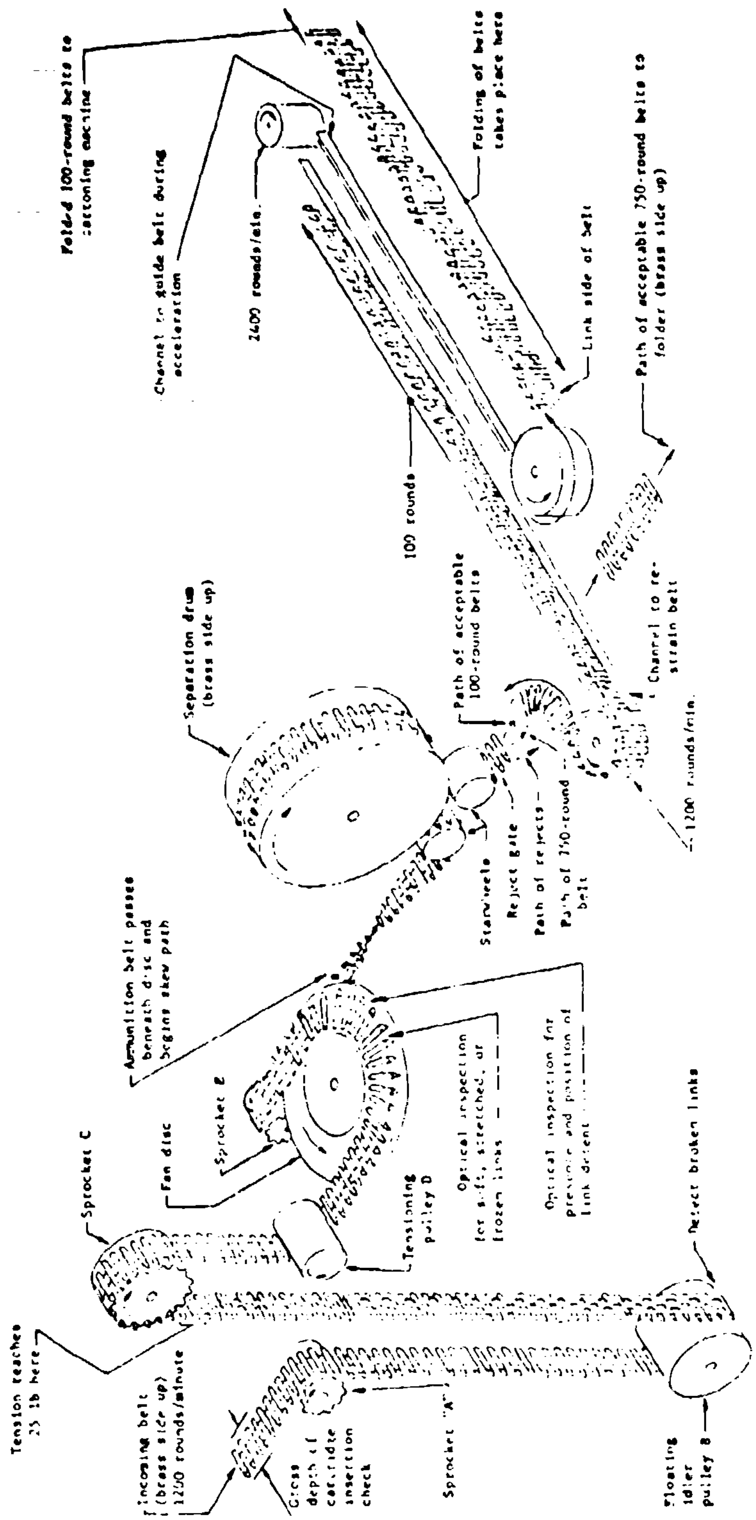
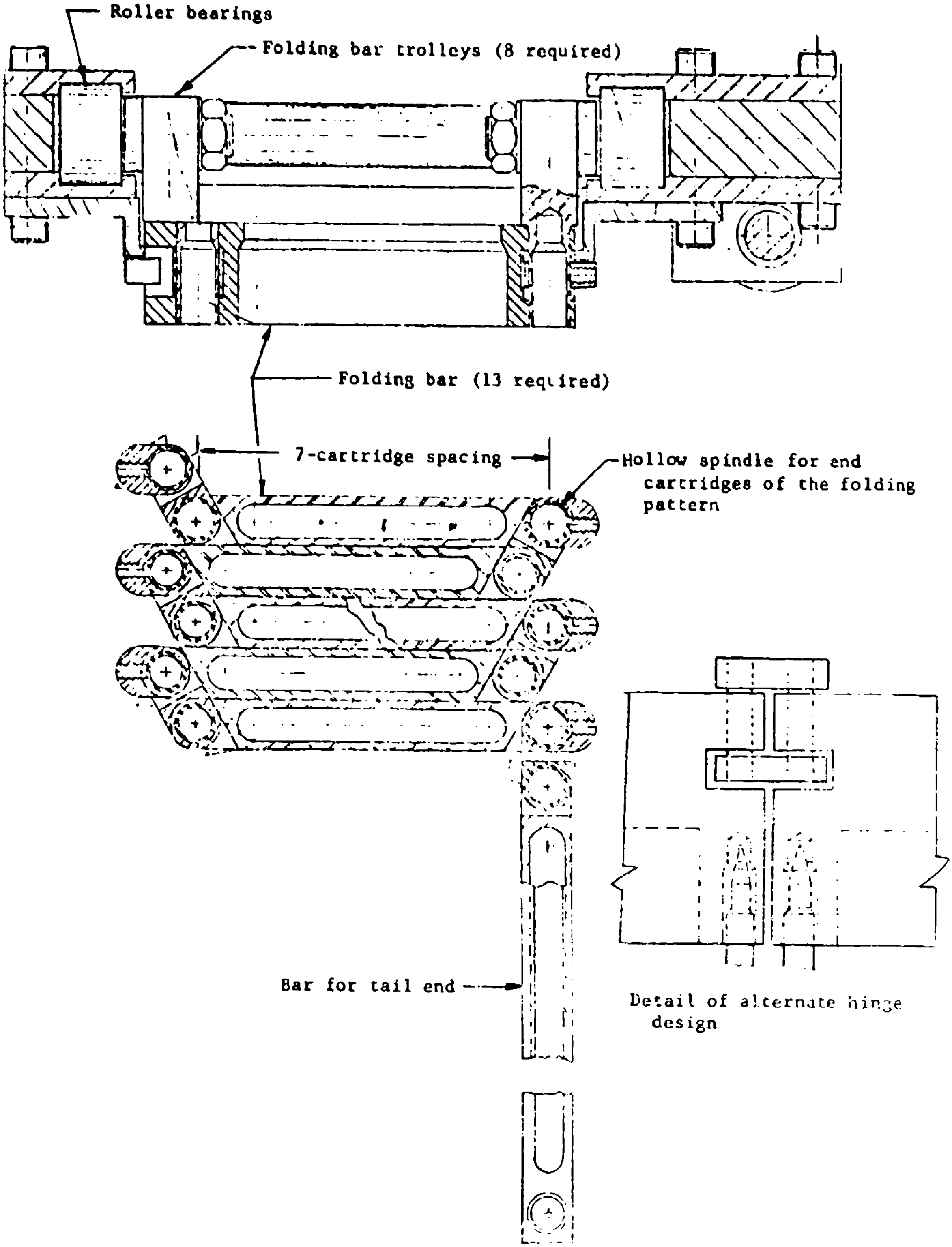


EXHIBIT XIV
Folding Bar Concept



Detail of alternate hinge design

EXHIBIT XV
Folded 100-Round Belt
For Functional Pack

Figure 1 - Folded 100-Round Belt

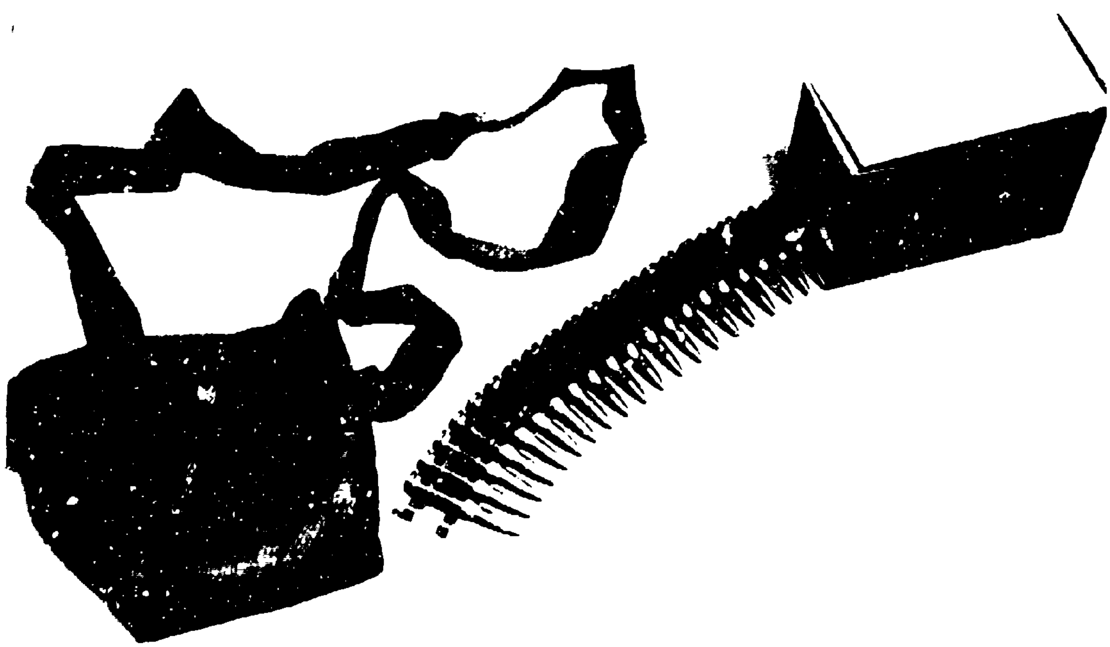
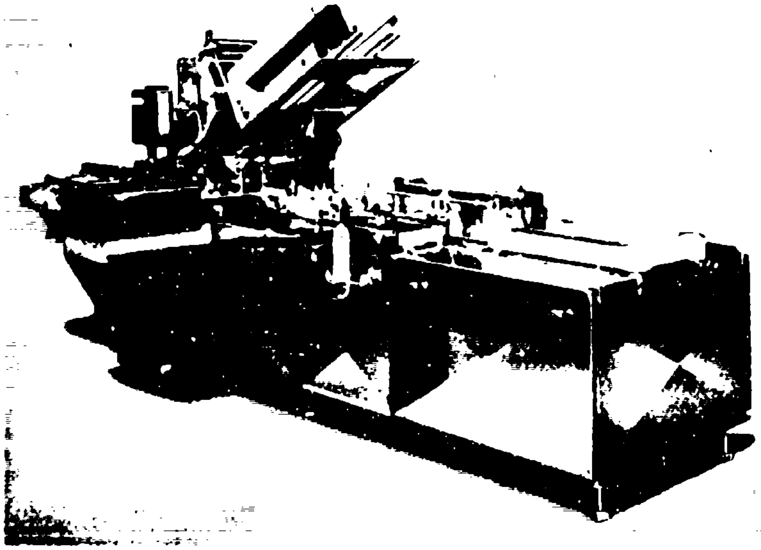


Figure 2 - Functional Pack

EXHIBIT XVI
Cartoning Subsystem



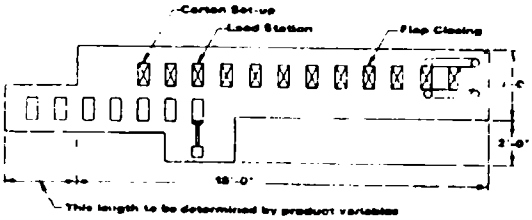


EXHIBIT XVII
Functional Pack Insertion
Into M19A1 Metal Containers

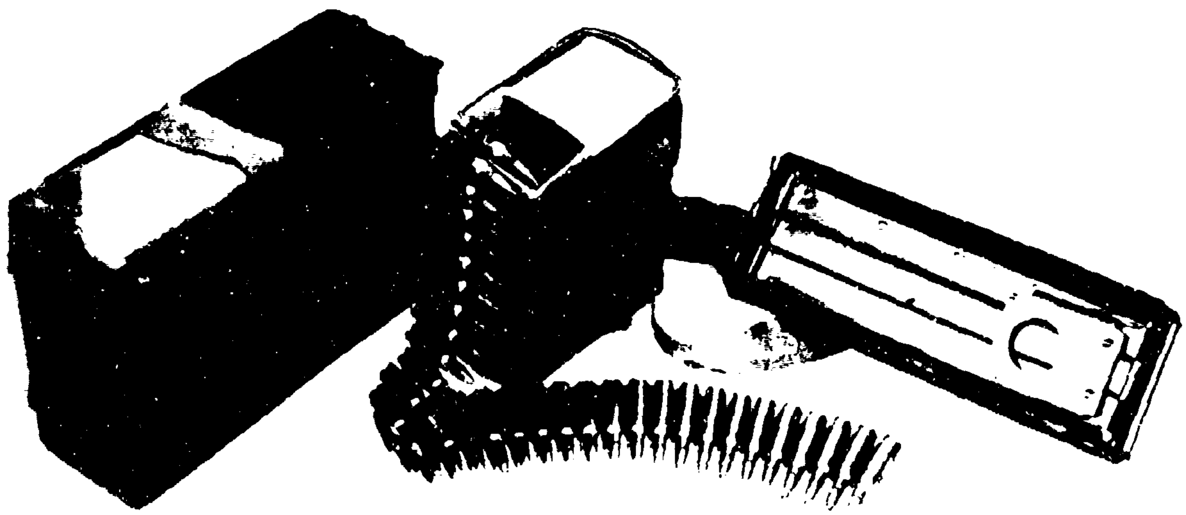


Figure 1 - 100-Round Belt Functional Packs
In M19A1 Metal Container

Figure 2 - Completed and marked M19A1
Metal Container

(8) M19A1 Metal Container Packing Subsystem

The completed functional packs are transferred to this subsystem where two (2) are inserted into the M19A1 metal container, illustrated in Exhibit XVII, Figure 2. The subsystem receives the metal containers, unlatches and opens the covers, inserts two (2) functional packs, and closes and latches the cover.

(9) M19A1 Metal Container Marking Subsystem

The completed M19A1 metal container is subsequently transferred to an off-the-shelf marking machine, as illustrated in Exhibit XVIII, Figure 1. The M19A1 container is marked on the top and side, as illustrated in Exhibit XVIII. Figure 2. The marked containers are subsequently transferred to the crating subsystem. At this point in the line, metal containers from two (2) additional lines shall be merged, however, not in the pilot submodule system.

(10) Crating Subsystem

With the potential output of two (2) additional M19A1 metal container packing lines merging prior to this subsystem, the crating machine must operate at a rate anywhere between 200 to 3600 rounds per minute. It shall operate on a demand basis, cycling at a rate of 4.5 crates per minute. The crating subsystem shall perform the following operations:

- Receive M19A1 metal containers with the latches leading in groups of four (4),
- Alternate the latches end-for-end and assemble the four (4) containers side-by-side, as illustrated in Exhibit XIX, Figure 1,
- Insert separators and assemble end fillers and crate ends,
- Transfer assembled unit and set on crate development,
- Fold crate development around assembled unit to near-closed configuration, and
- Transfer near-completed crate to an off-the-shelf crate closing machine for completing crate closure.

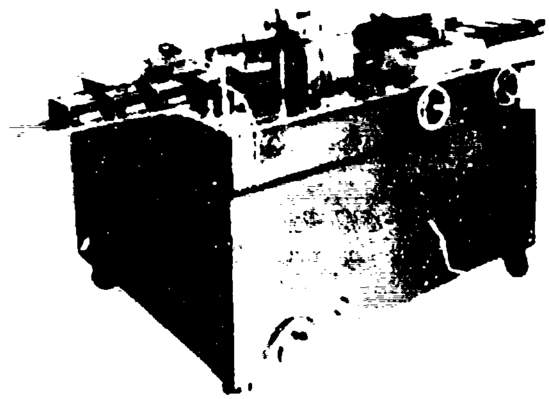


Figure 1 - Off-the-Shelf Marking Machine

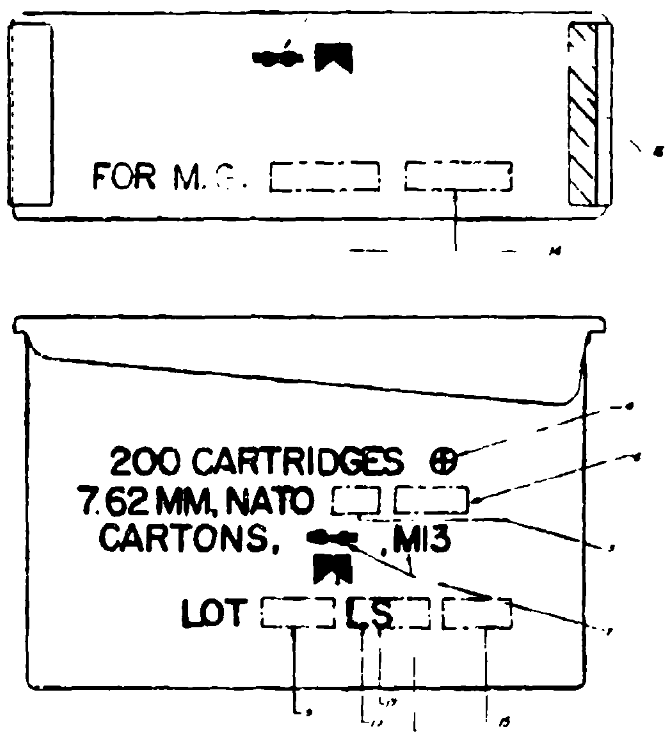


Figure 2 - M19A1 Metal Container Markings

EXHIBIT XIX
Crating Subsystem

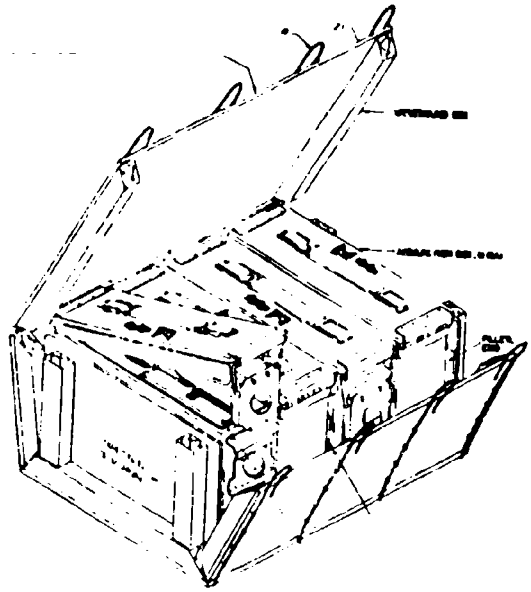


Figure 1 - Assembled Crate

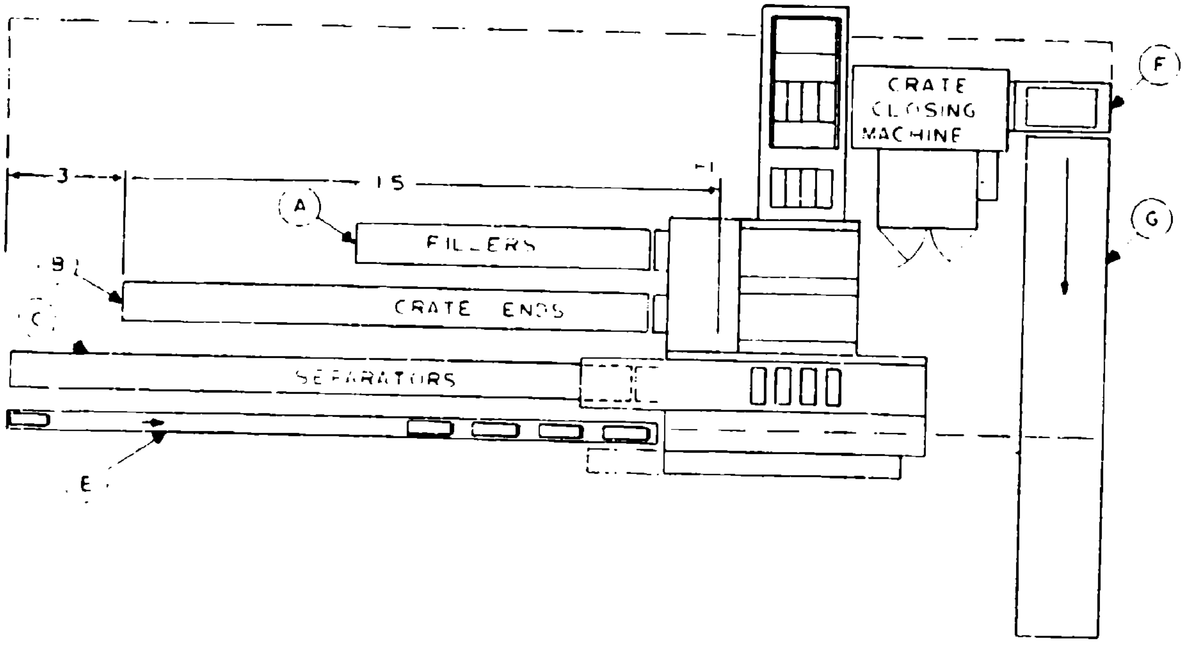


Figure 2 - Crating Subsystem Layout

This subsystem is also being developed by Battelle under a subcontract. A layout of the crating subsystem is illustrated in Exhibit XIX, Figure 2. The completed crate is subsequently conveyed to another marking subsystem for marking the top, end, and side. This same marking subsystem shall be used for the 750-round belt pack, and shall be described in a subsequent paragraph. Returning to the output of the linked belt inspection subsystem, the 750-round belts are diverted to the 750-round belt packing line.

(11) <u>750-Round Belt Folding Subsystem</u>

The 750-round belt shall be folded as illustrated in Exhibit XX. Whereas the design of this subsystem has not yet been initiated, the most promising concept for this operation is the festoon approach, as illustrated in Exhibit XXI.

(12) <u>Corrugated Sleeve and Separator Insertion Subsystem</u>

Cardboard separators are inserted between every other layer of folded belt and the entire folded unit is wrapped in a corrugated sleeve, as illustrated in Exhibit XXII.

(13) <u>M548 Metal Container Packing Subsystem</u>

Two (2) completed corrugated sleeve packs, as illustrated in Exhibit XXIII, Figure 1, are inserted in a M548 metal container. This subsystem receives the containers, unlatches and removes the cover, inserts two (2) sleeved 750-round belts, and replaces and latches the cover. At this point in the submodule system, the two (2) packing lines merge for the subsequent marking operation.

(14) <u>Crate and M548 Metal Container Marking Subsystem</u>

Both the wirebound crate and the M548 metal container require markings on the top, side and end, as illustrated in Exhibit XXIV. Both are sufficiently similar in dimension that a single off-the-shelf marking machine, as illustrated in Exhibit XXV, can perform both operations with tooling changes. This includes changing the inking systems because the crate requires black markings and the M548 yellow.

(15) <u>Inspection and Car Seal Application</u>

This station shall incorporate a manual inspection for the integrity of the pack and quality of the outside markings. The inspector shall manually apply a seal to both the wirebound crate and the M548 metal containers.

EXHIBIT XX
Folded 750-Round Belt

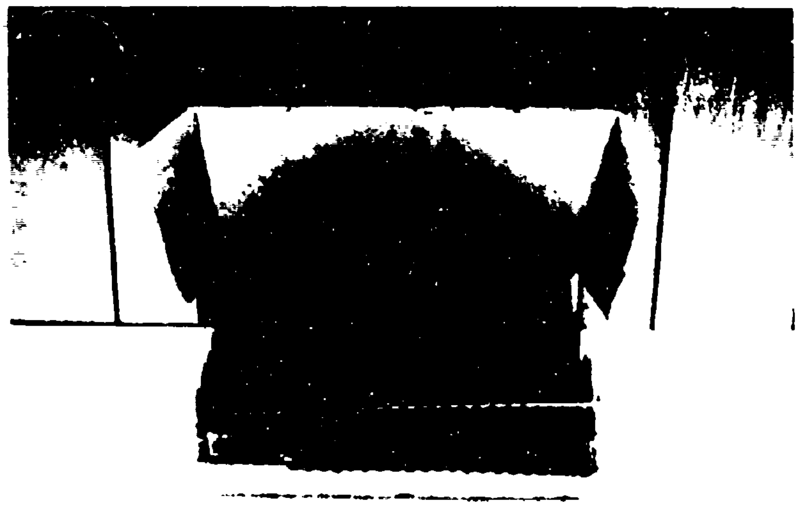


EXHIBIT XXI
Festoon Belt
Folding Concept

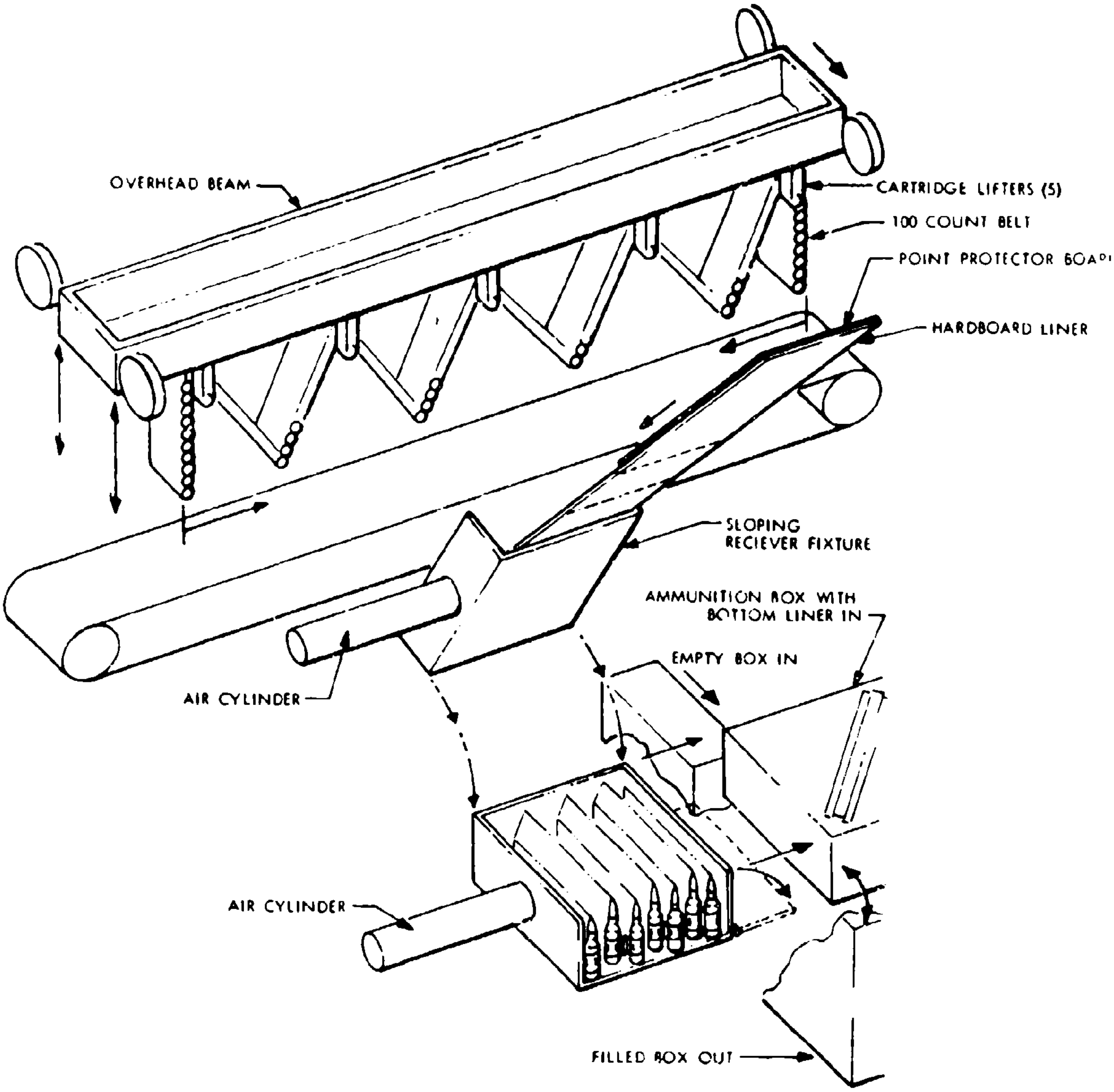


EXHIBIT XXII
Corrugated Sleeve and Separator Insert Subsystem

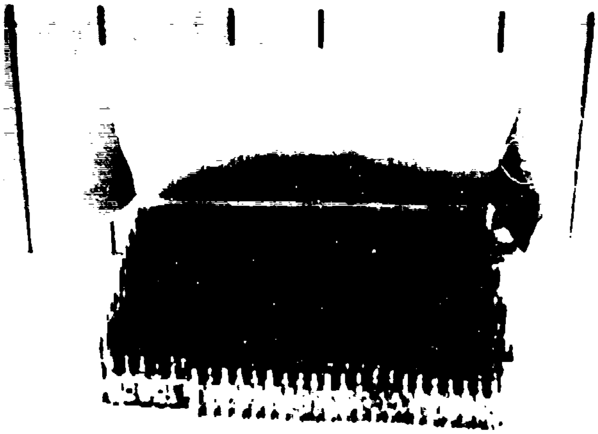


Figure 1 - 750-Round Belt Placed In Sleeve With Separators

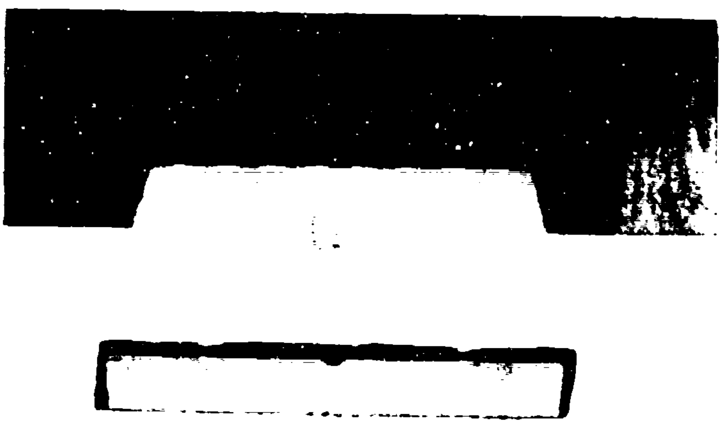


Figure 2 -Completed 750-Round Sleeve Pack

EXHIBIT XXIII
M548 Metal Container
Packing Subsystem

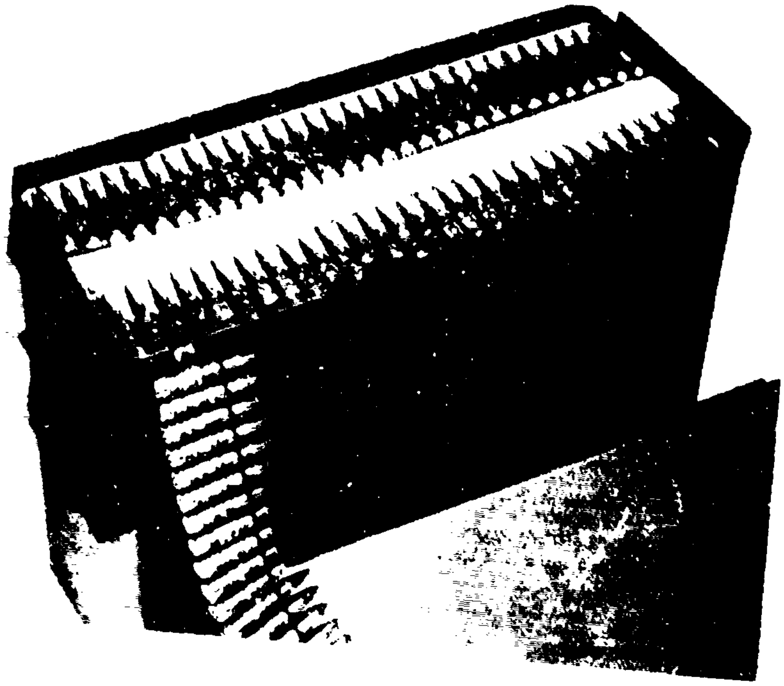


Figure 1 - Arrangement of Two (2) Sleeved 750-Round Belts In M548 Metal Container

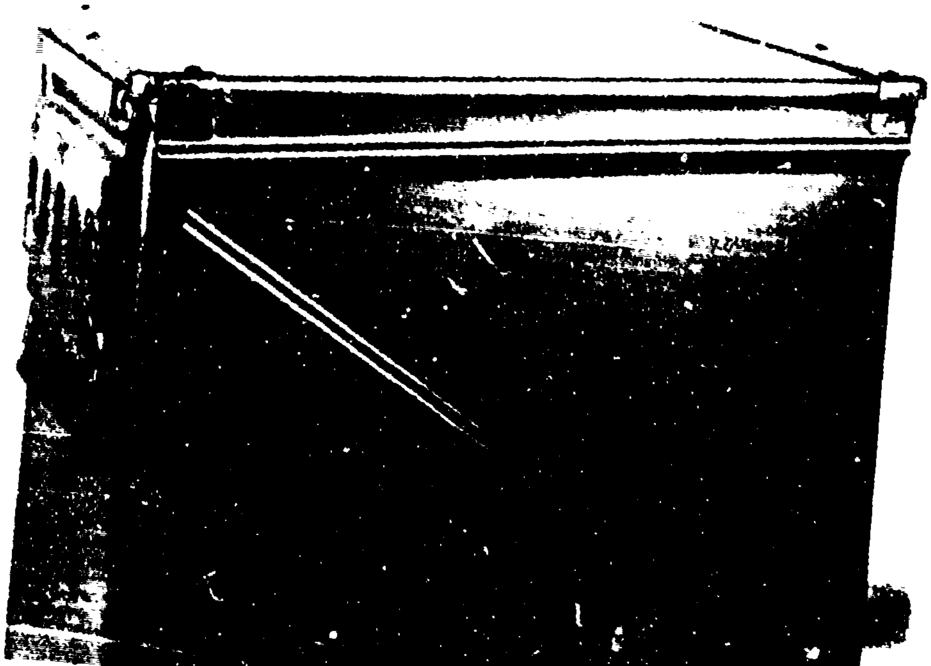


Figure 2 - Completed and Unmarked M548 Metal Container

EXHIBIT XXIV
Marking Requirements For
Wirebound Crate and M548
Metal Container

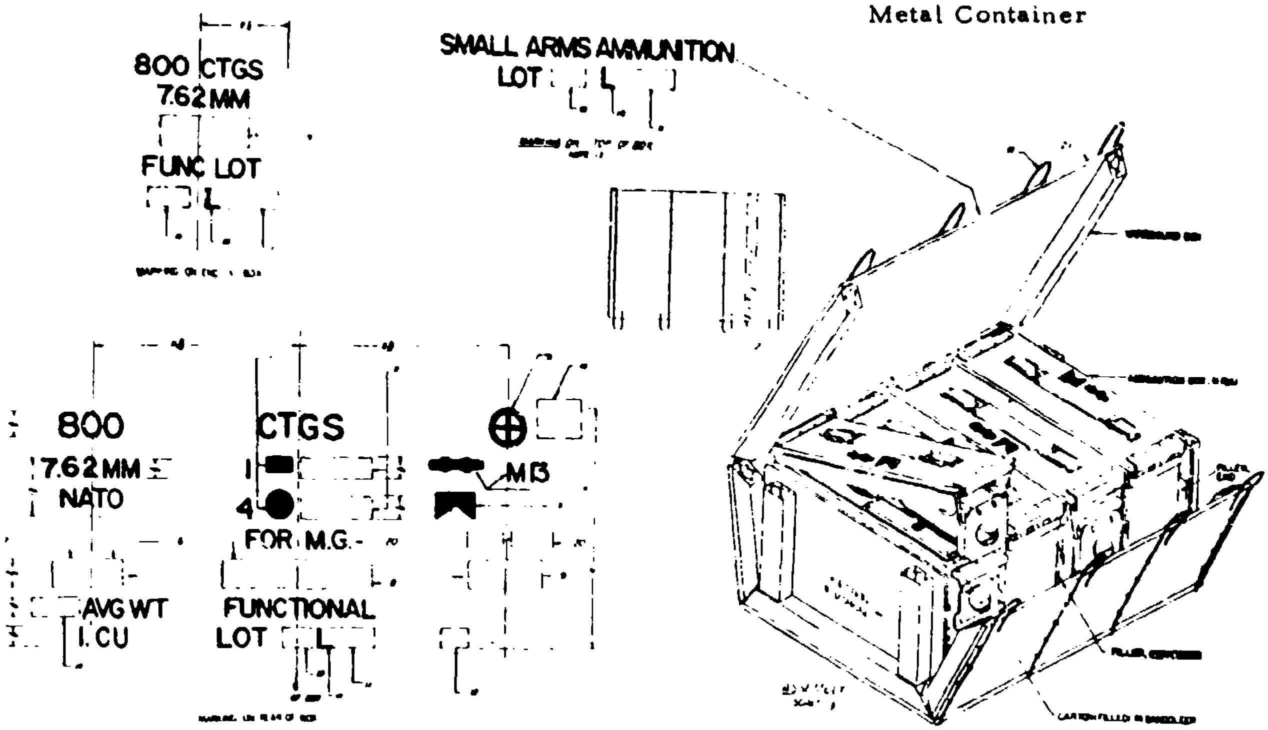


Figure 1 - Wirebound Crate Markings

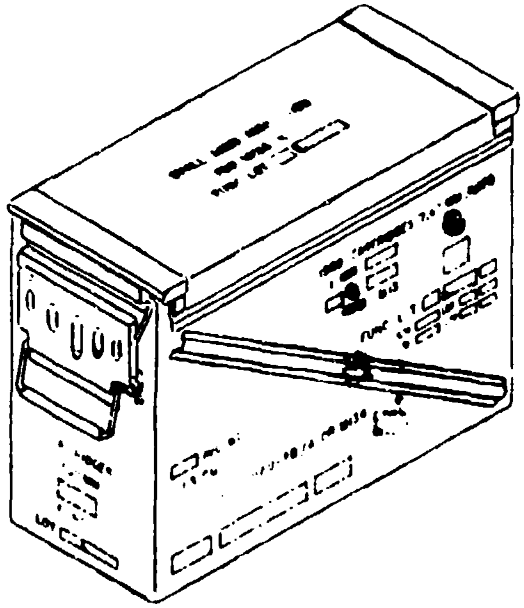
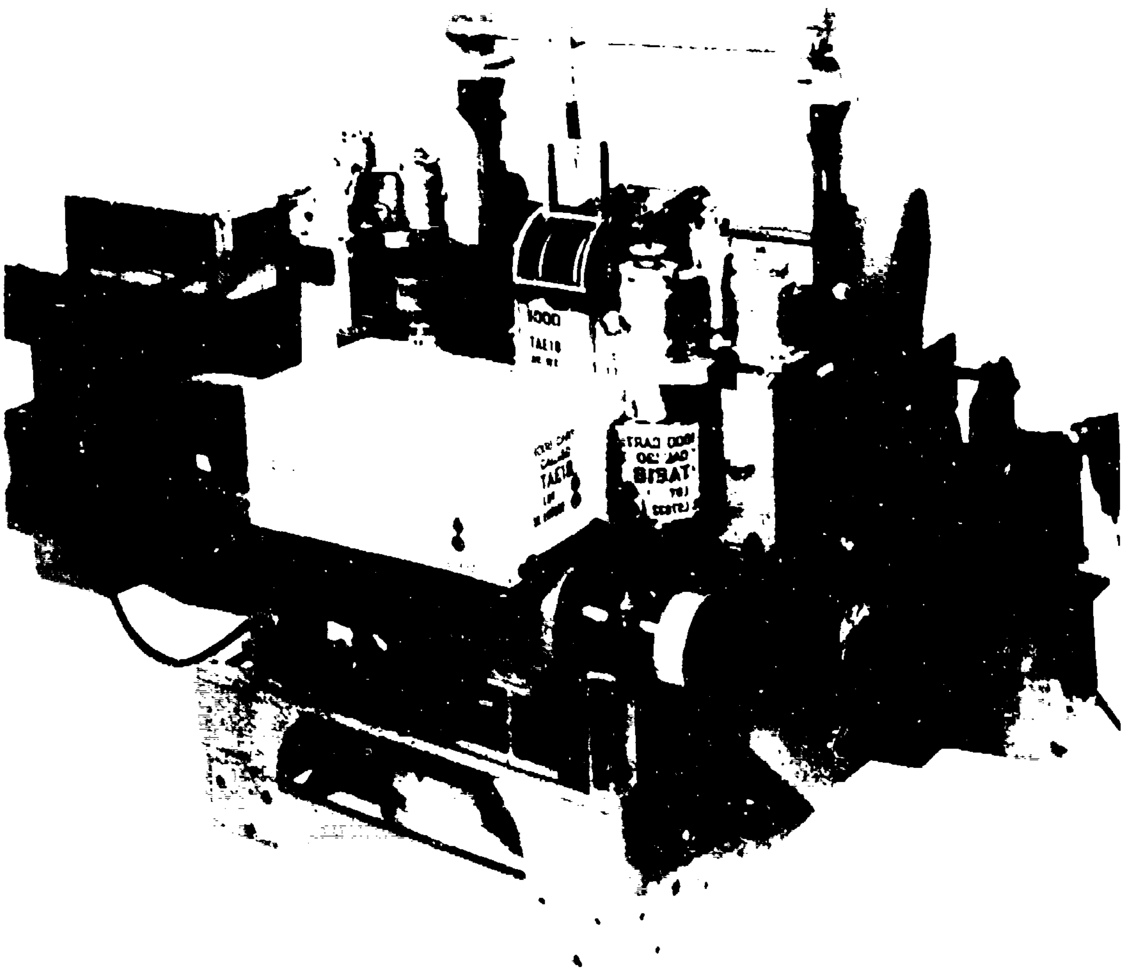


Figure 2 - M548 Metal Container Markings

EXHIBIT XXV
Three Side Marking
Subsystem



(16) Crate Inversion

The pallet pattern for the wirebound crates calls for the bottom layer of crates to be placed on the pallet with the tops of the M19A1 metal containers oriented downward. This gives added stability to the completed pallet load. Therefore, the first nine (9) crates to be stacked on pallet shall be inverted. All crates shall, however, be conveyed through this station in order to maintain their long-axis direction of flow to the subsequent palletizing operation. The M548 metal container shall not be conveyed through this station, but shall undergo a 90 degree reorientation so as to enter the palletizer in the short-axis direction of flow

(17) Palletizing Subsystem

The palletizing subsystem, as illustrated in Exhibit XXVI, is a standard off-the-shelf palletizer. The four (4) different palletizing configurations shall be accomplished through a punch tape control, whereby pallet configurations are changed merely by inserting the proper mylar tape. All four load configurations are palletized on the standard MUCOM 40 x 48 pallet.

(18) Horizontal Strapping Subsystem

The horizontal and vertical strapping subsystem comprise a standard off-the-shelf strapping machine. They must be separated, however, because the M548 metal container pallet patterns require dunnage be applied after horizontal strapping and before vertical strapping.

(19) Dunnage Application

The dunnage application operation is currently programmed to be a manual operation. It can be automated at a later date without much difficulty if it proves to be cost-effective.

(20) Vertical Strapping Subsystem

The vertical strapping subsystem shall apply straps over the dunnage of the M548 pallet loads and directly over the vertical strapping of the wirebound crate pallet configurations. A typical off-the-shelf strapping machine is illustrated in Exhibit XXVII. This is the last subsystem in the Submodule System. The completed pallets are discharged onto a roller conveyor where they shall be removed by a lift truck, or conveyed directly to a plant storage area.

EXHIBIT XXVI
Palletizing Subsystem

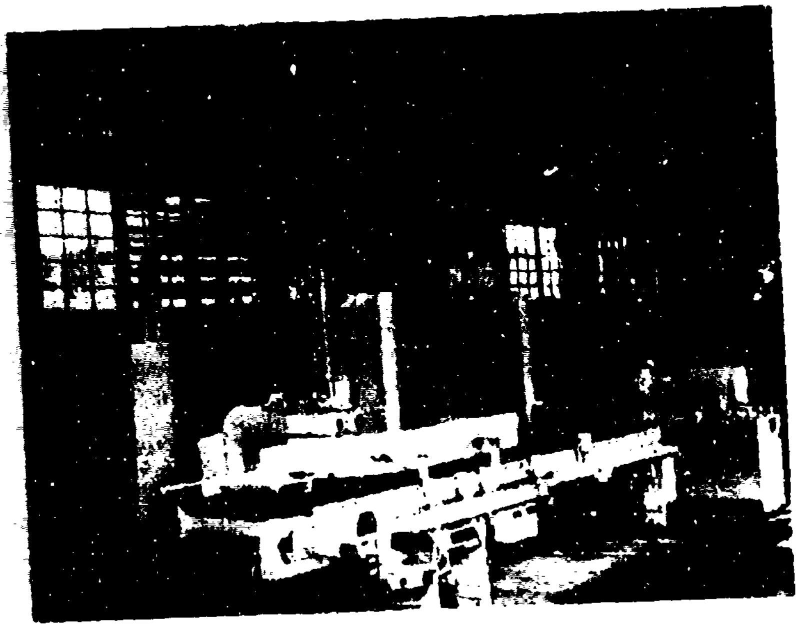


EXHIBIT XXVI

Palletizing Subsystem

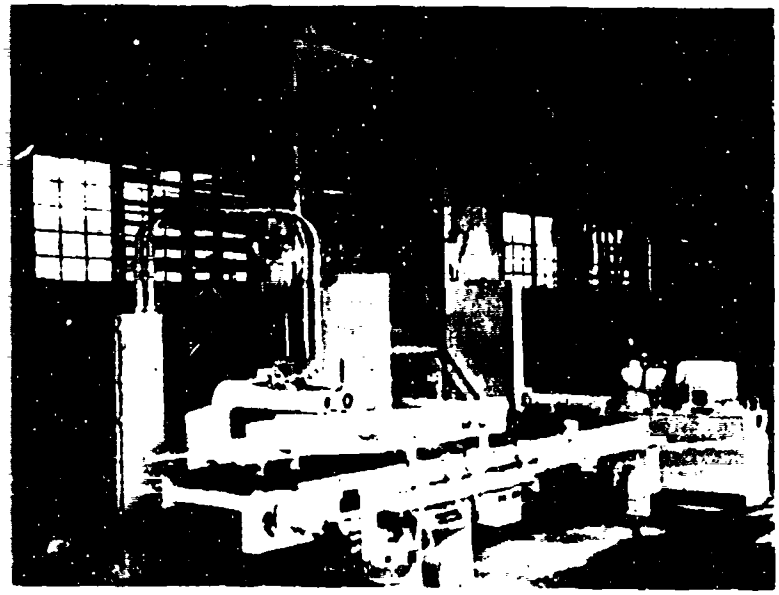
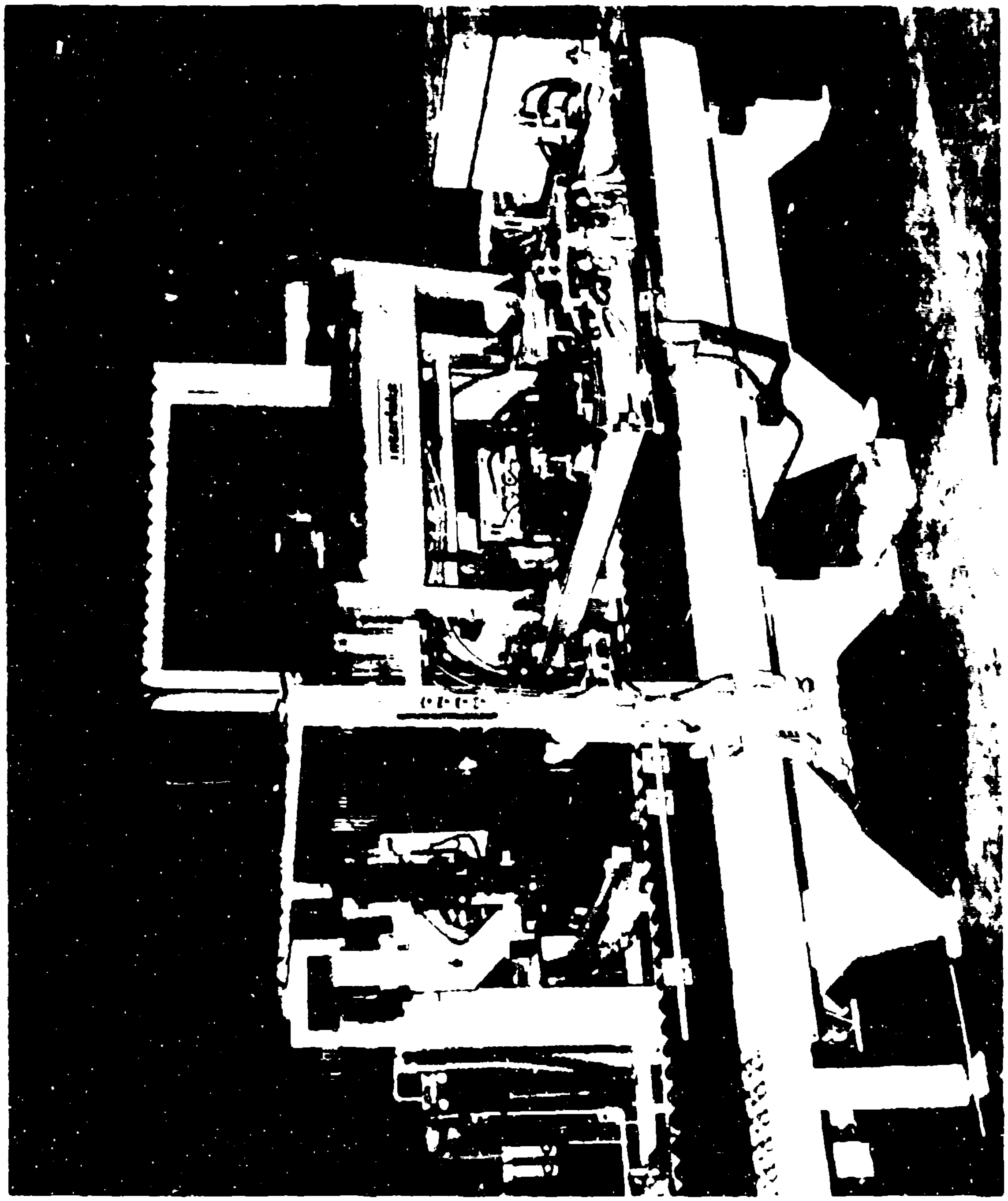


EXHIBIT XXVII

Strapping Subsystem



3. FEASIBILITY WORK PRIOR TO SUBMODULE SYSTEM INTEGRATION

(1) Linked Belt Inspection and 100-Round Folding

A feasibility study and test apparatus was developed by Battelle Memorial Institute for inspecting and folding discrete 100-round belts, as illustrated in Exhibit XXVIII, Figure 1. This has subsequently been redefined as a continuous operation with Battelle participating as a Subcontractor in the development of these two subsystems.

(2) Metal Container Opening and Closing

Battelle performed a feasibility study and developed test apparatus for opening and closing the metal container for 5.56mm ammunition, as illustrated in Exhibit XXVIII, Figure 2. The container is almost identical to the M19A1, which enables us to incorporate that technology into the Submodule System.

(3) Crating

Battelle also performed a feasibility study and developed test apparatus for automatically crating the 5.56mm metal containers, as illustrated in Exhibit XXVIII, Figure 3. The 5.56mm crate is of similar design to the 7.62mm wirebound crate, even though it contains only two (2) metal containers. Battelle is participating as a Subcontractor in the development of the Crating Subsystem for the Submodule System.

(4) Cartridge Intermix and Linking

Design and Development, Inc. performed a feasibility study and built an engineering model for the cartridge intermix and linking operation. The model performed up to a rate of 1700-rounds per minute where its highest required rate was 1200-rounds per minute. The feasibility model is illustrated in Exhibit XXIX. Design and Development, Inc. was subsequently awarded the prime contract to build and install the pilot Submodule System at the Lake City AAP.

4. ASSOCIATED AMMUNITION PACKAGING DEVELOPMENTS BY DESIGN AND DEVELOPMENT, INC.

Design and Development, Inc. has performed other developmental ammunition packaging assignments for both Frankford and Picatinny Arsenals.

EXHIBIT XXVIII
Battelle Feasibility Work

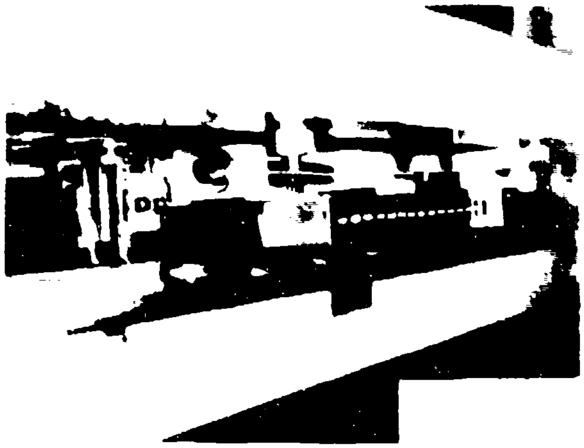


Figure 1 - Discrete 100-Round Belt Inspection and Folding Feasibility Apparatus

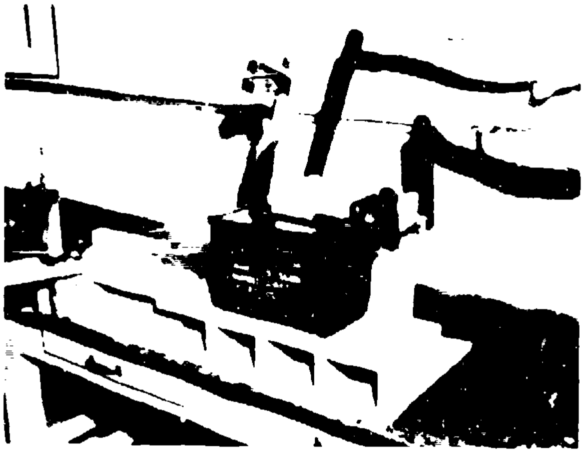


Figure 2 - Metal Container Opening And Closing Feasibility Apparatus

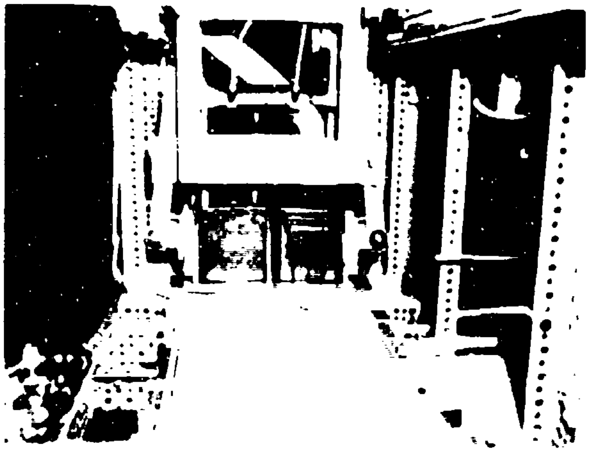
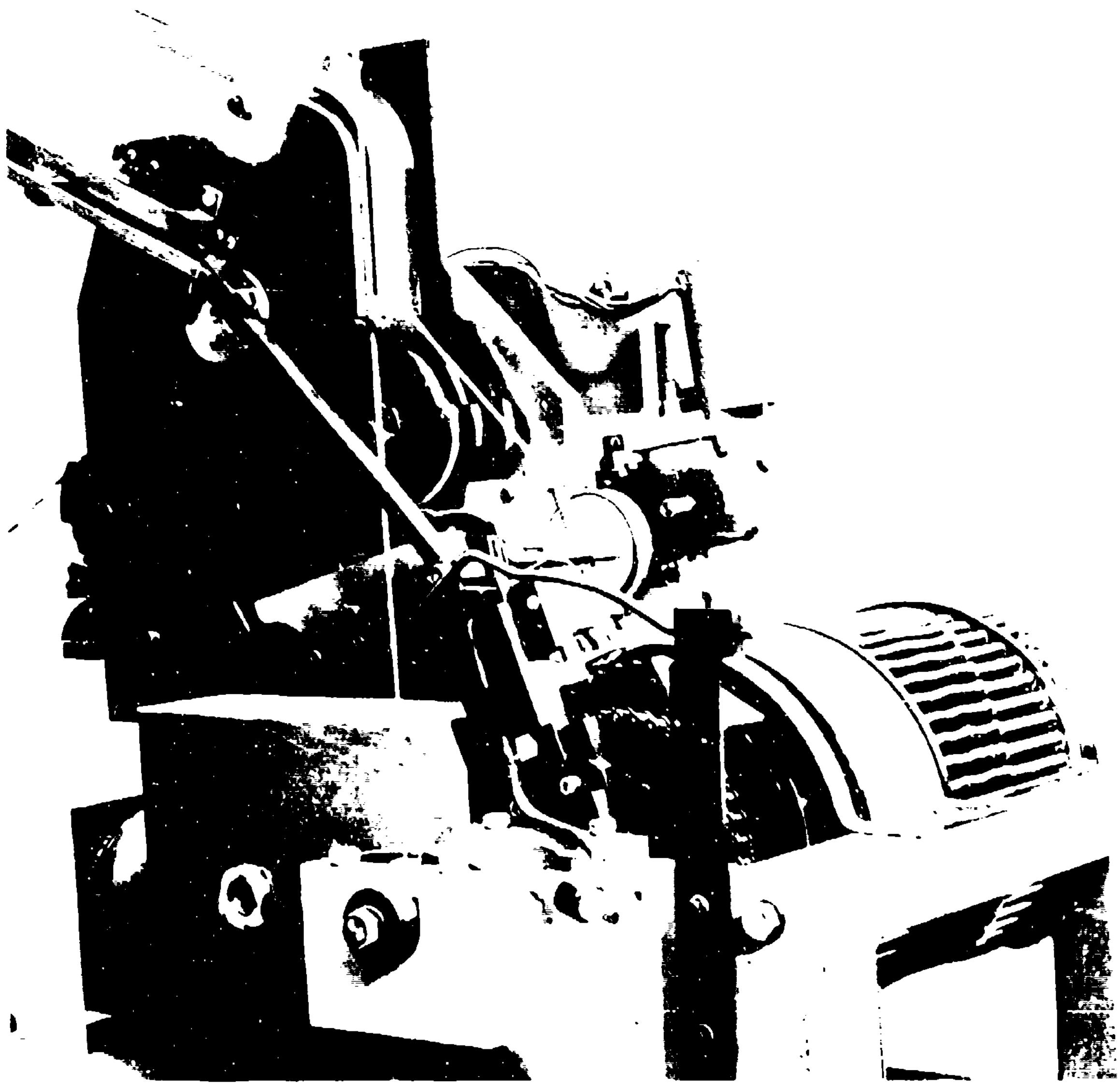


Figure 3 - Crating Apparatus

EXHIBIT XXIX
Design and Development, Inc.,
Engineering Model for Cartridge
Intermix And Linking



(1) 5.56mm Cartoning System

A program was conducted to prove the feasibility of cartoning 5.56mm cartridges at a rate of 1200 rounds per minute. The program resulted in prototype system, as illustrated in Exhibit XXX, which exceeded the 1200 PPM required rate. System functions included feeding separators from a hopper, filling the separators with cartridges, and inserting the filled separator into a carton.

(2) 5.56mm Clipping System

This assignment entailed clipping ten (10) rounds of 5.56mm ammunition at a rate of 1200 PPM. The system which was developed to perform this operation, illustrated in Exhibit XXXI, demonstrated the operation of diverting ten (10) cartridges, from a continuous in-feed, into the proper configuration for inserting the clip. The mechanical system performed successfully at the required rate.

(3) Automatic Propellant Increment Closing System

This program was conducted to demonstrate the feasibility of automatically closing filled increment bags for the 155mm, 175mm, and 8-inch propellant charges, by sewing. The system developed, illustrated in Exhibit XXXII, incorporated an industrial sewing machine mounted on a carrier which traced the correct contour of the seam.

(4) Automatic Propellant Increment Filling System

A production system for automatically processing the increments for the 155mm, 175mm, and 8-inch propellant charges was developed which included receiving the empty propellant bag from vendor packaging, introducing it into production so as to receive the premeasured propellant charge, filling the bag with propellant, closing the bag by sewing, inspecting the closure, check-weighing the completed increment, and diverting reject increments from the system. The program entailed the design, fabrication, and testing of working models to prove the feasibility of selected concepts. Other total system considerations included the engineering analysis of operations; reliability, maintainability, and human factors assessments; estimation of prototype and live module costs; and estimation of manufacturing cost reduction. The selected system concept is illustrated in Exhibit XXXIII.

EXHIBIT XXX
Design and Development, Inc.
5.56mm Cartoning System

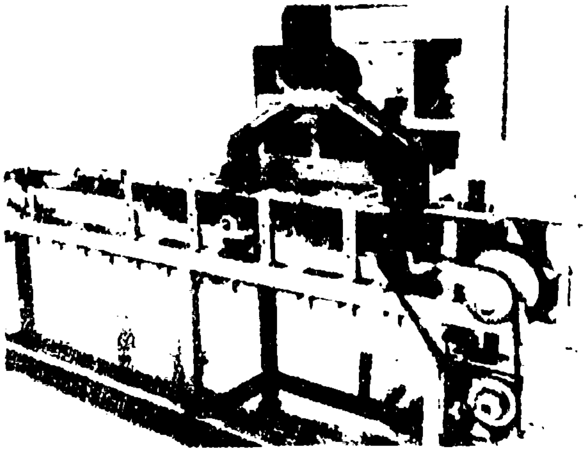


Figure 1 - Overall Cartoning System

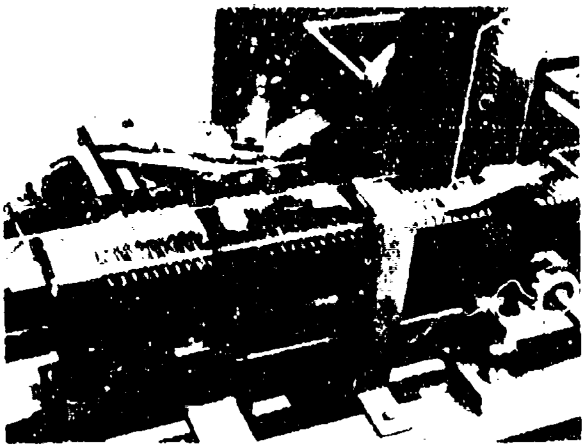


Figure 2 - Separator Feeding and Filling

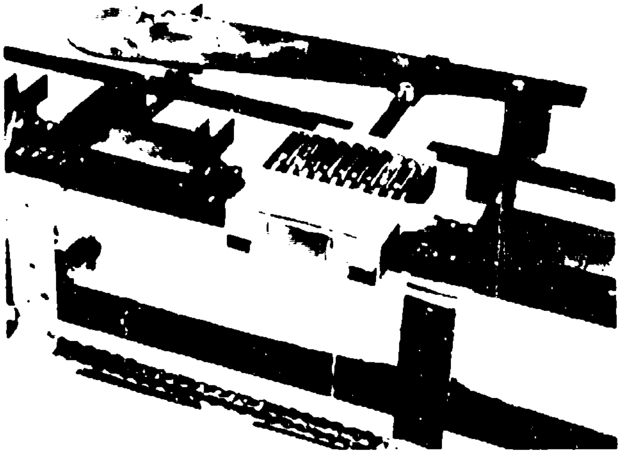


Figure 3 - Loaded Separator Insertion Into Carton

EXHIBIT XXXI
Design and Development, Inc.
5.56mm Clipping System

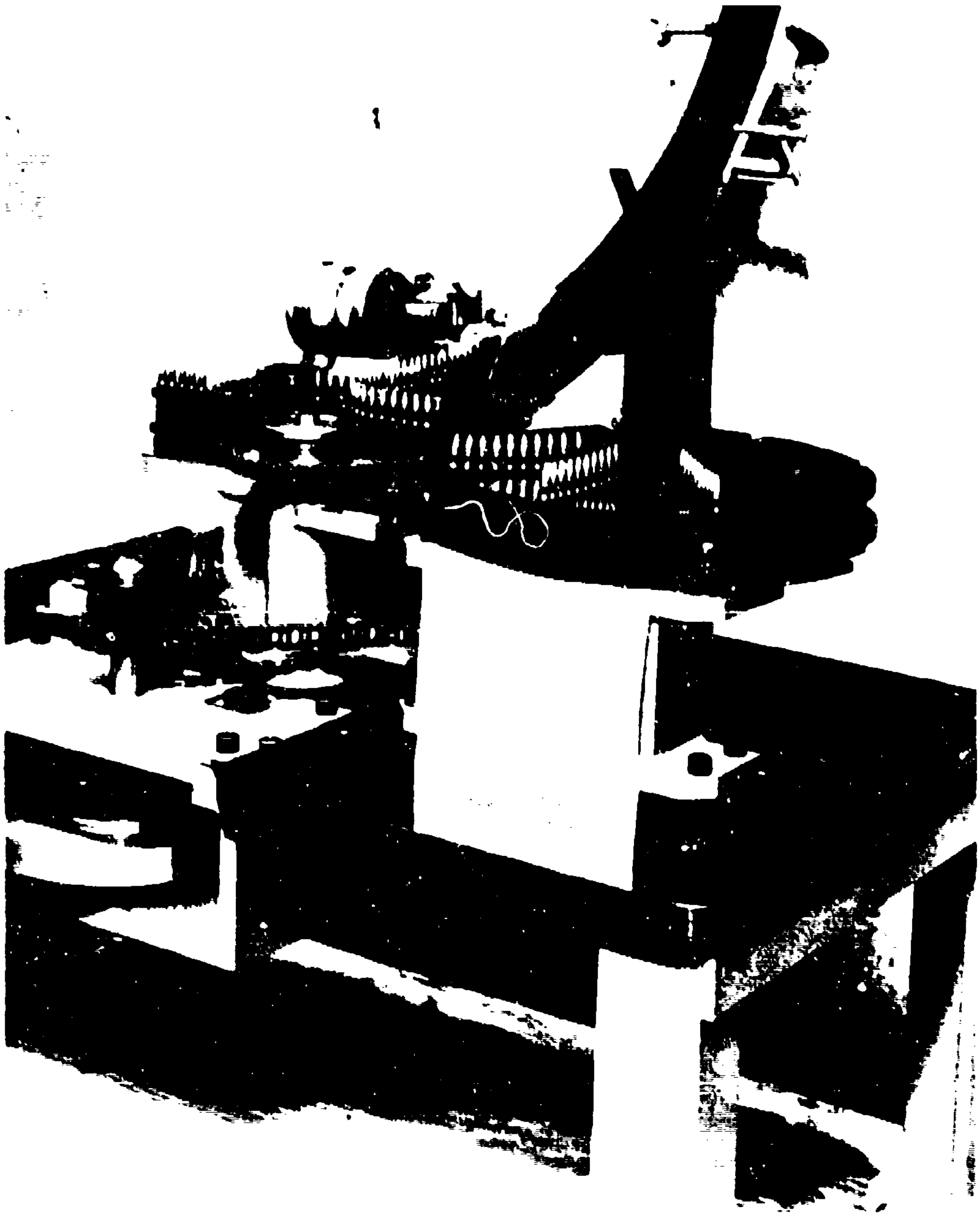


EXHIBIT XXXII
Design and Development, Inc.
Automatic Propellant
Increment Closing System

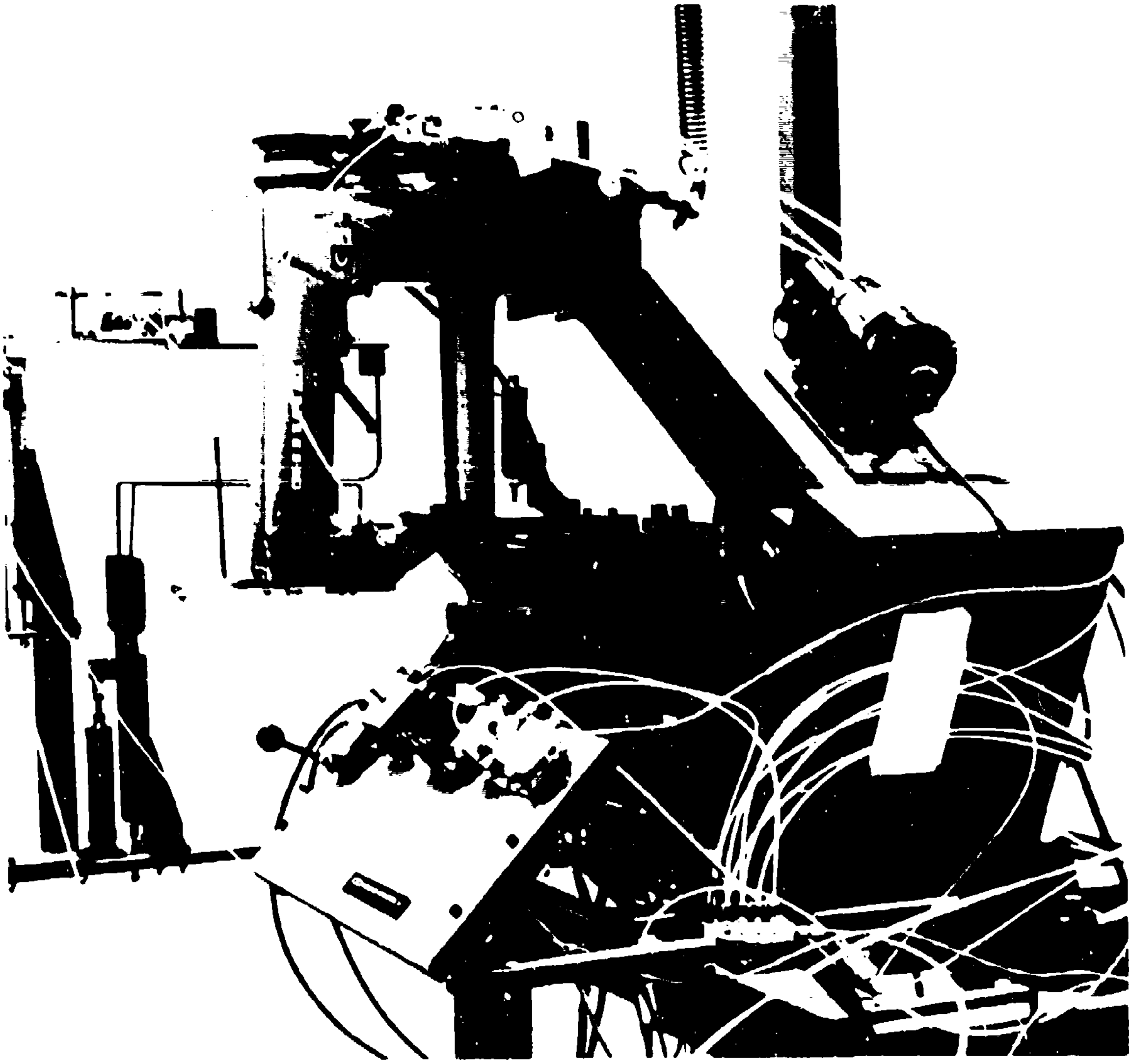
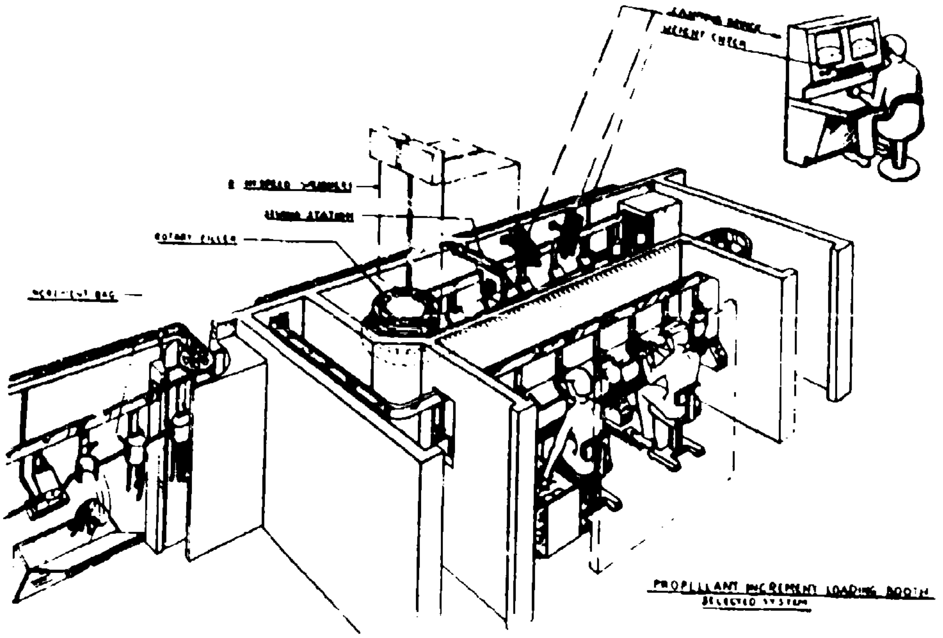


EXHIBIT XXXIII
Design and Development, Inc.
Automatic Propellant
Increment Filling System



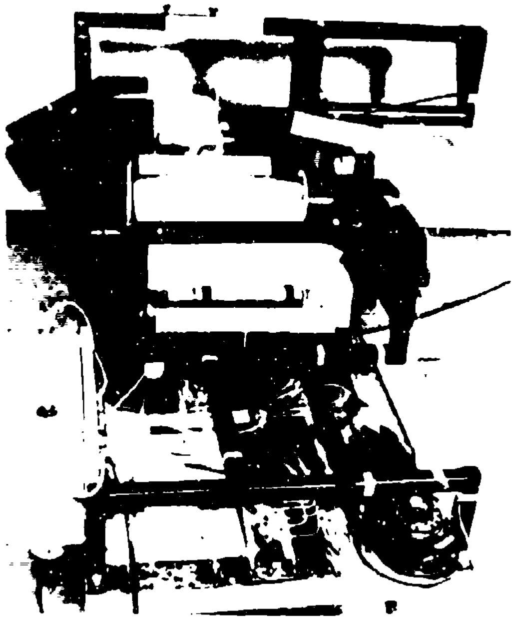
(5) Automatic Assembly, Inspection and Packaging Propellant Charges

This packaging assignment entailed assembling completed propellant increments, inspecting the completed charge, and automatically packaging the charges in metal cannisters. Various engineering models were developed, as illustrated in Exhibit XXXIV, to demonstrate particular functional areas of the system. The charges were for the 155mm, 175mm, and 8-inch projectiles.

(6) System to Load Pad and Core Type Igniter Charges

A feasibility and experimental verification program was conducted to design and develop a concept to automatically load the core and pad type igniter charges for the 155mm, 175mm, and 8-inch propellant charges. The operations to be mechanized for the pad type igniter included introducing an empty pad with propellant bag into production; transferring a premeasured amount of igniter powder to the fill funnels; blowing the contents of the fill funnel into the pad; closing the pad by sewing; sewing the pad closure to the propellant bag; check-weighing and inspecting the seam of the completed igniter pad; and discharging the completed igniter charge to the acceptable or reject conveyor. The operations to be mechanized for the core-type igniter included introducing an empty core into production; transferring a premeasured amount of igniter powder into the fill funnel; blowing the contents of the fill funnel into the core and tamping; inserting the igniter ribbon into the core; closing the core with the ribbon in place by sewing; check-weighing and inspecting the seam of the completed igniter core; and discharging to acceptable or reject conveyor. The selected concept is illustrated in Exhibit XXXV.

EXHIBIT XXXIV
Design and Development, Inc.
Automatic Assembly, Inspection
And Packaging Propellant Charges



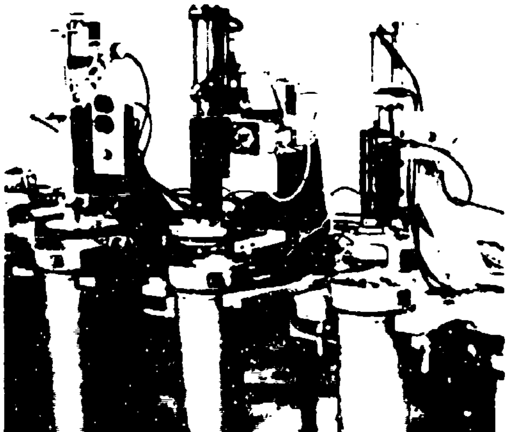
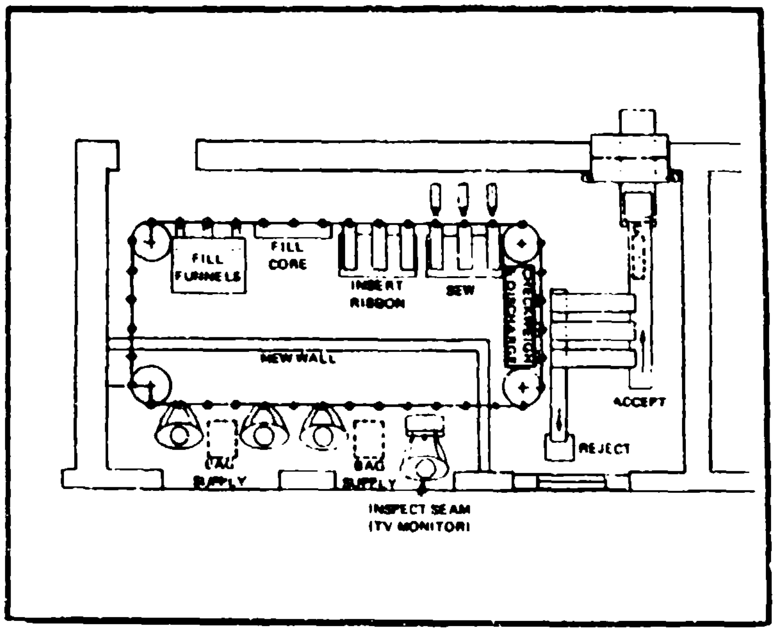


EXHIBIT XXXV
Design and Development, Inc. System To Load Pad And Core Type Igniter Charges



CORE IGNITER CHARGE LOADING

THREE OPERATORS ATTACH IGNITER CORE BAGS TO CARRIERS OUTSIDE THE CRITICAL AREA. THREE CARRIERS INDEX INTO THE CRITICAL AREA AND BETWEEN STATIONS SIMULTANEOUSLY.

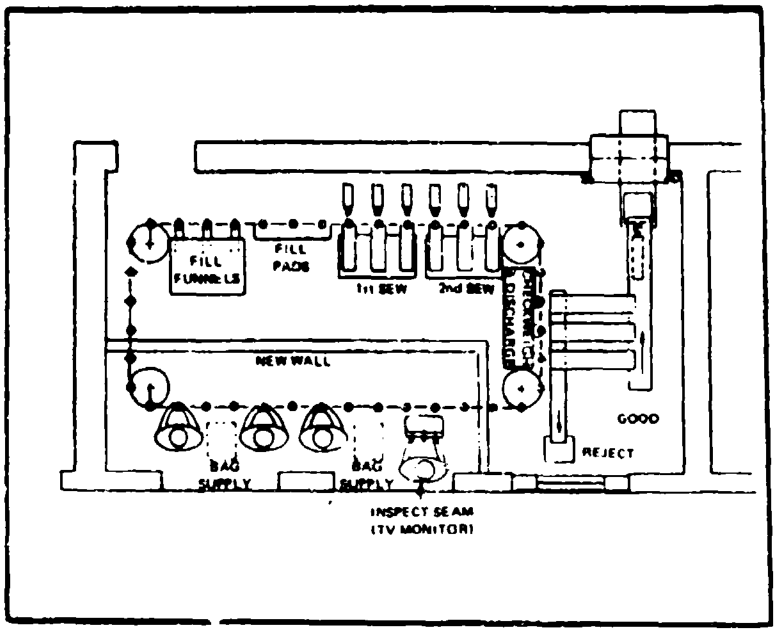
STATION 1 - DISCHARGE MEASURED AMOUNTS OF POWDER INTO THREE CARRIER FUNNELS.

STATION 2 - BLOW AND TAMP POWDER INTO THREE IGNITER CORES.

STATION 3 - INSERT RIBBON INTO CORE.

STATION 4 - SEW CORES CLOSED WITH RIBBON IN PLACE. INSPECT SEAM AT A REMOTE LOCATION BY MEANS OF CLOSED CIRCUIT TELEVISION.

STATION 5 - CHECKWEIGH THREE CORES AND DISCHARGE ACCORDINGLY



PAD IGNITER CHARGE LOADING

THREE OPERATORS ATTACH BAGS TO BAG CARRIERS OUTSIDE THE CRITICAL AREA. THREE CARRIERS INDEX INTO THE CRITICAL AREA AND BETWEEN STATIONS SIMULTANEOUSLY.

STATION 1 - DISCHARGE MEASURED AMOUNTS OF POWDER INTO THREE CARRIER FUNNELS.

STATION 2 BLOW AND TAMP POWDER INTO THREE PADS.

STATION 3 - SEW PADS CLOSED.

STATION 4 - SEW PAD CLOSURE TO INCREMENT BAG

STATION 5 - CHECKWEIGH THREE BAGS AND DISCHARGE ACCORDINGLY.

D. C. MALM

BOOZ ALLEN APPLIED RESEARCH

PRESENTS

"MODERNIZATION OF MATERIALS HANDLING IN AMMUNITION LOADING PLANTS"

BOOZ.ALLEN APPLIED RESEARCH

*CAPABILITIES AND EXPERIENCE IN THE AMMUNITION, EXPLOSIVES AND SOLID ROCKET MOTOR FIELD INCLUDES:

- MATERIALS HANDLING STUDIES IN LAP AND EXPLOSIVES PLANTS
- EXPLOSIVES EXPLORATORY DEVELOPMENT REVIEWS
- EXPLOSIVES PACKAGING ANALYSIS
- SOLID ROCKET MOTOR DESIGN AND PROCESSING ANALYSIS
- DEPOT OPERATIONS ANALYSIS
- MATERIALS CONTROL SYSTEM PLANNING
- RELIABILITY ANALYSIS
- SAFETY/HAZARDS ANALYSIS
- POLLUTION ABATEMENT ANALYSIS
- TRANSPORTATION STUDIES – AIR, LAND, WATER
- PROJECT MANAGEMENT SUPPORT

*COPIES OF QUALIFICATIONS BROCHURE AVAILABLE UPON REQUEST

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- — ARMY, NAVY, AIR FORCE
- — FEDERAL, STATE & LOCAL GOVERNMENT AGENCIES
- — COMMERCIAL CLIENTS

TODAY'S PRESENTATION INCLUDES:

- REQUIREMENTS AND SCOPE OF LOADING PLANT STUDIES
- PHASE I APPROACH
- TYPICAL PHASE I RESULTS
- PHASE II APPROACH
- TYPICAL CONCEPTS ANALYZED
- TYPICAL RECOMMENDED MODERNIZATION

(WORK CONDUCTED DURING PAST 3 YEARS UNDER CONTRACTS WITH PICATINNY ARSENAL, DOVER, NEW JERSEY)

TWO-PHASED STUDY

PHASE I

- PLANT SURVEYS
- DATA ASSIMILATION
- PHASE I REPORTS (5 PLANTS)

PHASE II

- IDENTIFY IMPROVEMENTS
- ANALYZE ALTERNATIVES
- REVIEW FINDINGS AT LAP PLANTS
- DEVELOP RECOMMENDATIONS
- FINAL REPORTS (4 PLANTS)

TYPES OF AMMUNITION ITEMS INCLUDED

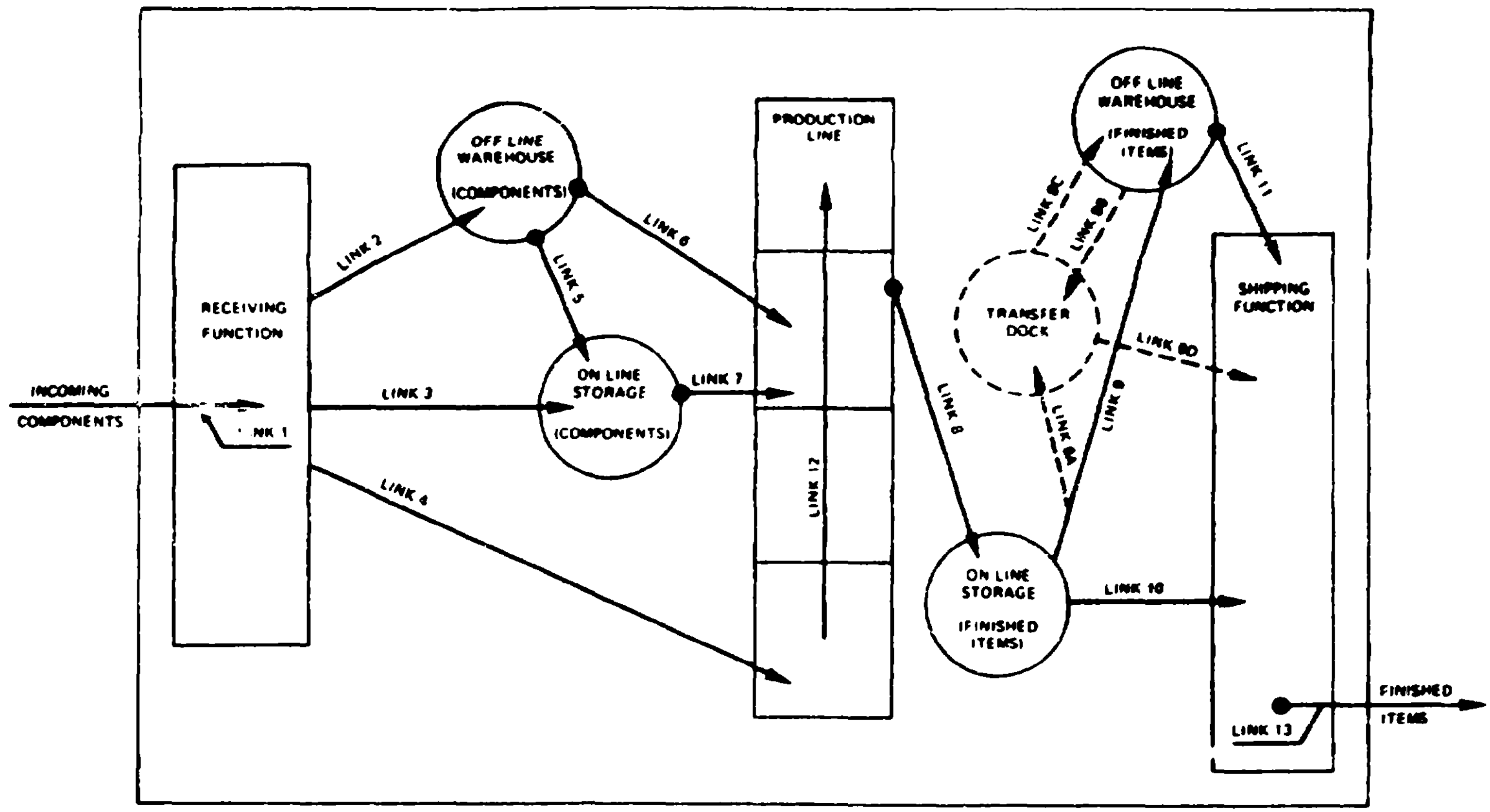
- 40MM CARTRIDGE
- 60MM CARTRIDGE
- 90MM CARTRIDGE
- 105MM CARTRIDGE
- 106MM CARTRIDGE
- 152MM CARTRIDGE
- 165MM CARTRIDGE
- 155MM PROJECTILE
- 175MM PROJECTILE
- 8 INCH PROJECTILE
- 66MM ROCKET
- 2.75 INCH ROCKET
- DEMO CHARGES
- MINE
- HAND GRENADE
- CBU 24 B/B
- ADAPTER, BOOSTER, BOMB
- DETONATORS, PRIMERS, RELAYS
- FUZES, ACTIVATORS, TRACERS

PHASE I APPROACH

OPERATIONS INCLUDED

- RECEIVING INERTS AND EXPLOSIVES
- STORAGE
- DELIVERY TO LINES
- HANDLING ON LINES
- TRANSFER OF FINISHED ITEMS TO STORAGE
- SHIP OUT OF FINISHED ITEMS

TYPICAL MATERIALS FLOW THRU A LAP PLANT

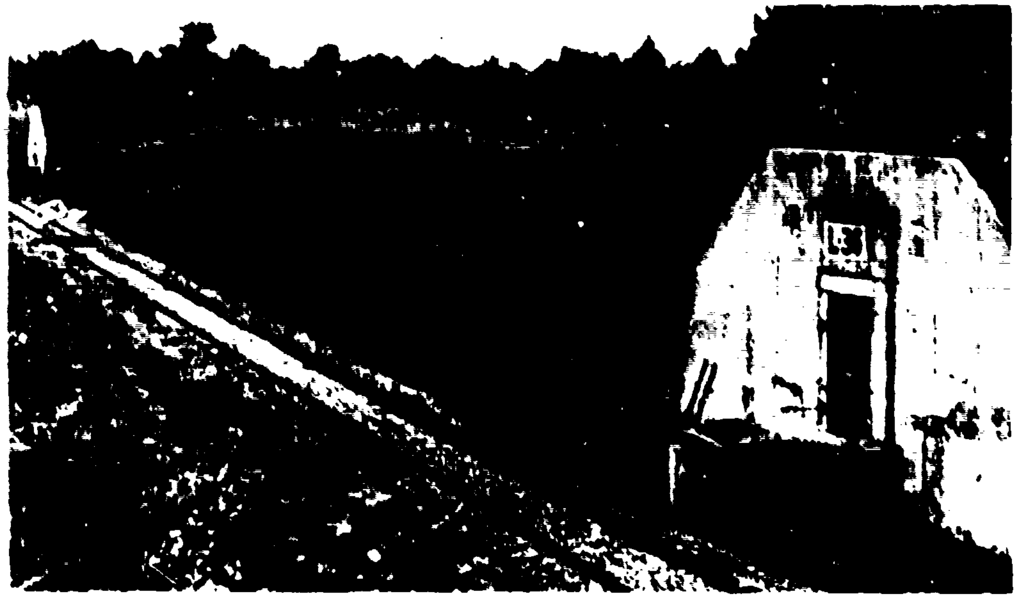


PHASE I APPROACH

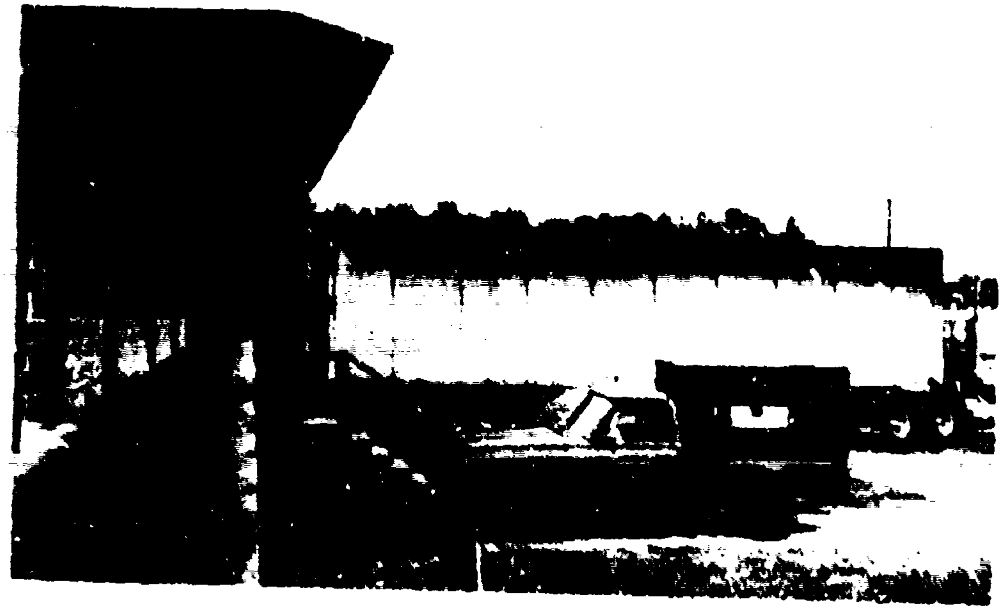
DATA ASSIMILATED

- OVERALL PLANT MATERIALS FLOW
- PRODUCTION LINE MATERIALS FLOW
- MATERIALS HANDLING METHODS
- LABOR REQUIREMENTS
- UNIT COSTS FOR MATERIALS HANDLING OPERATIONS
- SUMMARIES OF SAFETY WAIVERS
- SUMMARIES OF MODERNIZATION PROJECTS
- PACKAGING CHARACTERISTICS
- STORAGE CAPACITY
- SPACE REQUIREMENTS
- TENTATIVE IMPROVEMENT CANDIDATES

Horizontal movement on Line X by walkie transporter and hand truck is slow, requires a full-time operator, and limits loads to a single pallet load or less.



Igloo storage magazines in Yard L used for Composition B and other explosive storage are served only by rail, thus requiring incoming and outgoing truck shipments to be transferred to and from rail cars. Small magazine docks make forklift operations difficult and dangerous. Small doors and lack of lighting also restrict materials handling operations.



Limited overhead ramp clearances prevent the movement of double-stacked pallet loads - Line X, Building X-34, east ramp.

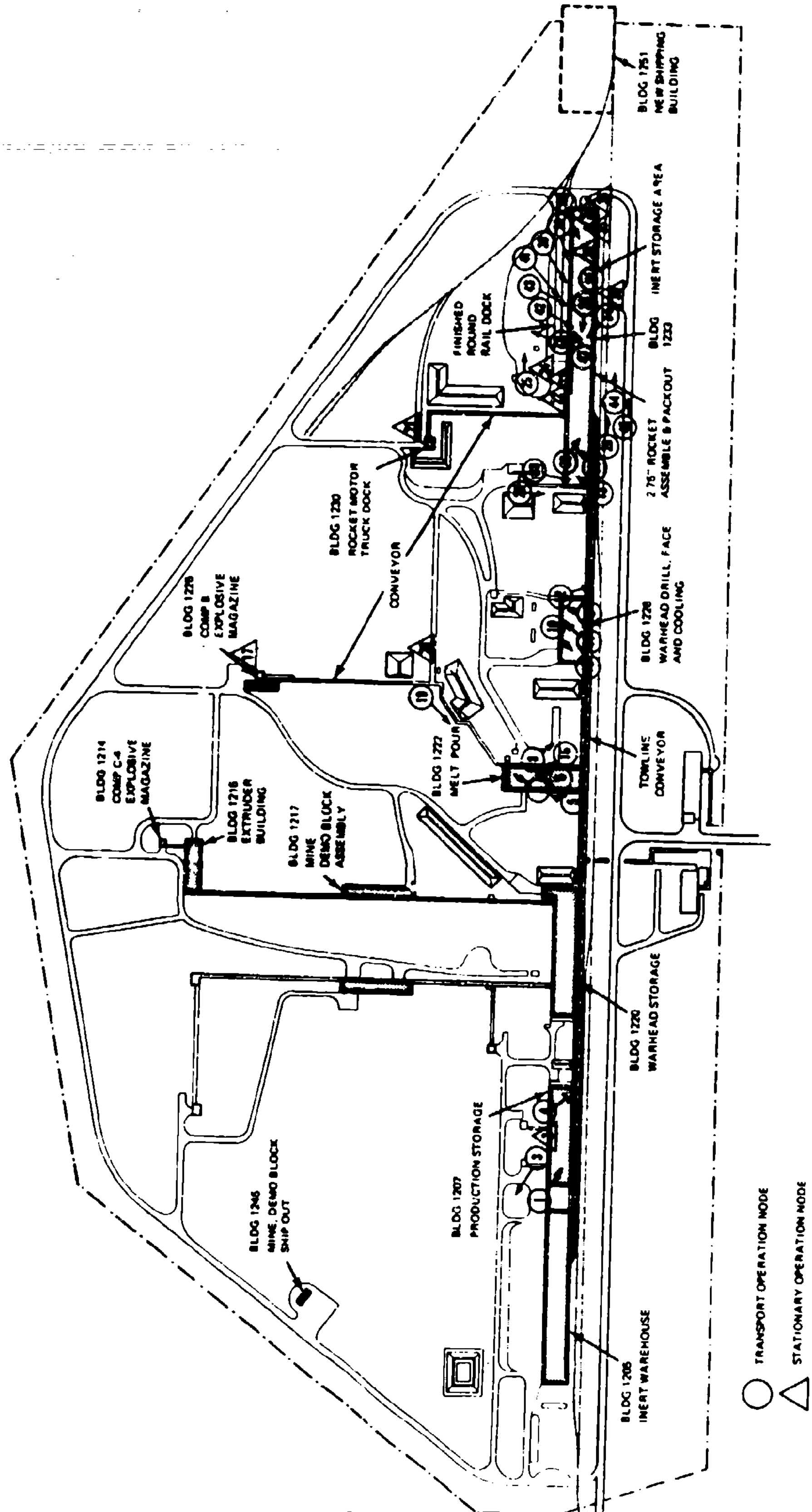
Materials Handling Labor and Equipment Cost at Louisiana Army Ammunition Plant fo

Operation	% Operation	Method & Crew Code	Unweighted	
			Man Hrs/ 1000 Rounds	Labor Cost $/1000 Rounds
Transport vendor shipment to area M1				
by rail	25	T1	0.35	1.160
by truck	75	T3	0	0
Unload carload at warehouse (M1)	25	1	0.74	2.072
Unload truckload at warehouse (M1)	75	1	0.88	2.464
Load rail to line at warehouse (M1)	100	2	0.71	1.988
Move rail to line(D) from warehouse(M1)	100	T1	0.132	0.338
Unload rail at line(D)	100	12	0.25	0.70
Move to production	100	13	0.25	0.70
Transport vendor shipment to warehouse				
by rail	25	T1	0.205	0.681
by truck	75	T3	0	0
Unload rail at warehouse	25	1	0.605	1.694
Unload truck at warehouse (M1)	75	1	0.627	1.756
Load rail to line(D) at warehouse	100	2	0.605	1.694
Move rail to line(D)	100	T1	0.09	0.302
Unload rail at line Bldg 1205	100	12	0.20	0.560
Move to production Bldg 1207	100	13	0.20	0.560

Total Materials Handling Cost Summary

for Charge Assembly Demo 183

Cost Category	Cost per 1000 Rounds (dollars)
On-Line Materials Handling Labor	417.17
Off-Line Materials Handling Labor	173.60
Total Materials Handling Labor	590.77
Fringe Benefits 33%	194.95
Total Labor	785.72
Equipment Cost On-Line	14.29
Equipment Cost Off-Line	15.81
Total Equipment Cost	30.10
Subtotal - Materials Handling Cost	815.82
G & A Overhead 55%	448.70
Total Materials Handling Cost	1,264.52


BLDG 1751
NEW SHIPPING BUILDING
INERT STORAGE AREA
FINISHED ROUND RAIL DOCK
BLDG 1233
2.75" ROCKET ASSEMBLE & PACKOUT
BLDG 1230
ROCKET MOTOR TRUCK DOCK
CONVEYOR
BLDG 1226
COMP B EXPLOSIVE MAGAZINE
CONVEYOR
BLDG 1228
WARHEAD DRILL, FACE AND COOLING
BLDG 1222
MELT POUR
TOWLINE CONVEYOR
BLDG 1214
COMP C-4 EXPLOSIVE MAGAZINE
BLDG 1216
EXTRUDER BUILDING
BLDG 1217
MINE DEMO BLOCK ASSEMBLY
BLDG 1220
WARHEAD STORAGE
BLDG 1207
PRODUCTION STORAGE
BLDG 1245
MINE, DEMO BLOCK SHIP OUT
BLDG 1205
INERT WAREHOUSE
TRANSPORT OPERATION NODE
STATIONARY OPERATION NODE

TENTATIVE IMPROVEMENTS

C. EQUIPMENT

- CONVEYORS FOR
  - UNLOAD, SEPARATION AND TRANSFER OF FIBER TUBES
  - EXTENSION TO ADDITIONAL OPERATIONS
  - TRANSFER OF PACKAGED AMMO TO SHIPPING DOCK
  - REPLACEMENT OF HAND CARTS

- PORTABLE EQUIPMENT INCLUDING
  - AUTOMATIC TOW TRACTORS FOR LONG DISTANCE MOVEMENTS
  - MANUAL TOW TRACTORS
  - FORK LIFT TRUCKS
  - SELF-PROPELLED, RIDER PALLET JACKS
  - PORTABLE RAMPS

- TRANSPORTATION EQUIPMENT SUCH AS
  - STRADDLE CARRIERS
  - RAIL CARS WITH ROLL-UP DOORS
  - SHUTTLE BED TRAILERS
  - AUTOMATIC, UNMANNED, SELF-PROPELLED RAIL VEHICLES

TENTATIVE IMPROVEMENTS

D. FACILITIES

CENTRALIZED [1] AND DECENTRALIZED RECEIVING AND STORAGE BUILDINGS

- INERT MATERIALS WAREHOUSES
  - PALLET ON PALLET
  - PALLET RACKS
  - AUTOMATED
- BULK EXPLOSIVES RECEIVING AND STORAGE MAGAZINES
- EXPLOSIVES COMPONENTS RECEIVING AND STORAGE MAGAZINES
- IN-PROCESS STORAGE MAGAZINES
- FINISHED AMMUNITION STORAGE AND SHIP OUT BUILDINGS AND YARDS
- MODIFICATIONS AND NEW
  - DOCKS
  - RAMPWAYS
  - DOORWAYS
  - APRONS

CENTRALIZED [1] AND DECENTRALIZED TRANSPORTATION

- RAIL TRACK AND CONTROLS FOR UNMANNED RAIL SHUTTLE VEHICLE
- SHUTTLE BED TRAILER
- RAIL ACCESS
- TRUCK ACCESS

(1) MILAN AND IOWA ONLY

THE PHASE II APPROACH

FOR 2-8-5 MOBILIZATION:

- CLASSIFY DEMAND — MATERIALS MOVEMENT AND ACCUMULATION
- IDENTIFY HIGH ANNUAL COST OPERATIONS
- SELECT IMPROVEMENT ALTERNATIVES
  - INITIAL SCREENING
  - DECENTRALIZED
  - CENTRALIZED
- ANALYZE SURVIVING ALTERNATIVES — COST, SAFETY, OTHER MERITS
  - METHODS
  - PACKAGING
  - EQUIPMENT
  - FACILITIES
- DEVELOP TENTATIVE RECOMMENDATIONS
- REVIEW TENTATIVE RECOMMENDATIONS AT LAP PLANTS
- FINALIZE RECOMMENDATIONS
- PRESENT FINAL BRIEFING
- PREPARE FINAL REPORTS

SPECIAL REQUIREMENTS

- DEMAND FROM 2-8-5 MOB SCHEDULE
- LABOR REQUIREMENTS FROM LAP STANDARDS
- FUTURE STANDARD PALLET – 36" X 44"
- EXCLUDES MELT-POUR AND PRODUCTION CONVEYOR HANDLING (AFTER PACKAGE OPENING)
- FUTURE LIFO INVENTORY CONTROL[1]
- DETERMINE PALLETIZATION IMPACT ON VENDORS
- INERT STORAGE FOR 10, 30 and 60 WORKING DAYS
- P&E STORAGE FOR [1] 60 WORKING DAYS [2]
- FINISHED ITEM STORAGE FOR [1] 90 WORKING DAYS [2]

(1) MODIFICATION TO CONTRACT

(2) ESTIMATES OF INVESTMENT COST FOR MILAN & IOWA ONLY

MATERIALS HANDLING COST SUMMARY
(INCLUDES FRINGE BENEFITS & G&A OVERHEAD)

PLANT	LINE	ITEM	MOBIL RATE (1000 Rds./Mo.)	ANNUAL COST ($1000)
MILAN	A	CART., 40MM, M384	1515	1348
	A	CART., 40MM, M385	60	37
	A	CART., 40MM, M576	420	340
	A	CART., 60MM, M49	600	1353
	A	FUZE, M564	300	306
	A	FUZE, M62	10	17
	A	FUZE, M91	80	143
	B	CART., 40MM, M397	200	502
	B	CART., 40MM, M406	1200	645
	B	CART., 40MM, M407	200	85
	B	CASE, CART., 40MM, M195	140	22
	B	HAND GRENADE, M67	550	639
	B	DEMO, CHARGE, M58	0.09	50
	B	PRIMER, M71	1923	307
	B	PRIMER, M32	877	79
	B	DELAY PLUNGER, M1	1830	354
	B	DELAY ELEMENT, M2	2000	66
	D	CBU 24 B/B	3.65	856
	X	CART., 105MM, M392	14	129
	X	CART., 105MM, M393	30	373
	X	CART., 105MM, M494	22	225
	X	CART., 105MM, M546	15.4	165
	X	CART., 106MM, M344	62	689
	X	CART., 106MM, M346	34	399
	X	CART., 106MM, M581	2.6	25
			TOTAL	9154

COST EVALUATION CRITERIA

(REFERENCE: DOD INSTRUCTION 7041.3)

- PRESENT WORTH METHOD
- 1973 COST (REF. LAP COST DATA AND BAAR SOURCES)
- CONSIDERS INVESTMENT, NON-RECURRING AND VARIABLE COSTS
- EXISTING INVESTMENT SUNK
- 10 PERCENT INTEREST RATE
- 10 YEAR EQUIPMENT ECONOMIC LIFE
- 25 YEAR FACILITIES ECONOMIC LIFE
- SAVINGS FROM VACATED FACILITIES
  - INERT STORAGE: $0.40 PER SQ. FT. PER YR.
  - EXPLOSIVE STORAGE: $0.80 PER SQ. FT. PER YR.
- LABOR COSTS INCLUDE FRINGE BENEFITS AND G&A OVERHEAD
- ECONOMIC MEASURE OF MERIT IS PAYBACK RATIO (P.R.) MUST EQUAL OR EXCEED = 1.0

$$\text{P.R.} = \frac{\text{PRESENT VALUE OF 10 YEAR SAVINGS}^{(1)}}{\text{PRESENT VALUE OF 10 YEAR INVESTMENT}^{(2)}}$$

(1) ANNUAL SAVINGS = EXISTING O&M COSTS - PROPOSED O&M COSTS

(2) PRESENT WORTH OF SALVAGE VALUE OF FACILITIES AT 10 YEARS DEDUCTED FROM INVESTMENT

RECOMMENDED MATERIALS HANDLING
MODERNIZATION CONCEPT
LOUISIANA AAP

Title: New On-Line Explosive Magazine for Line "D"

Objective: To Eliminate Double Handling of Composition "B" Explosives

Level: 2

Finished Ammunition Affected

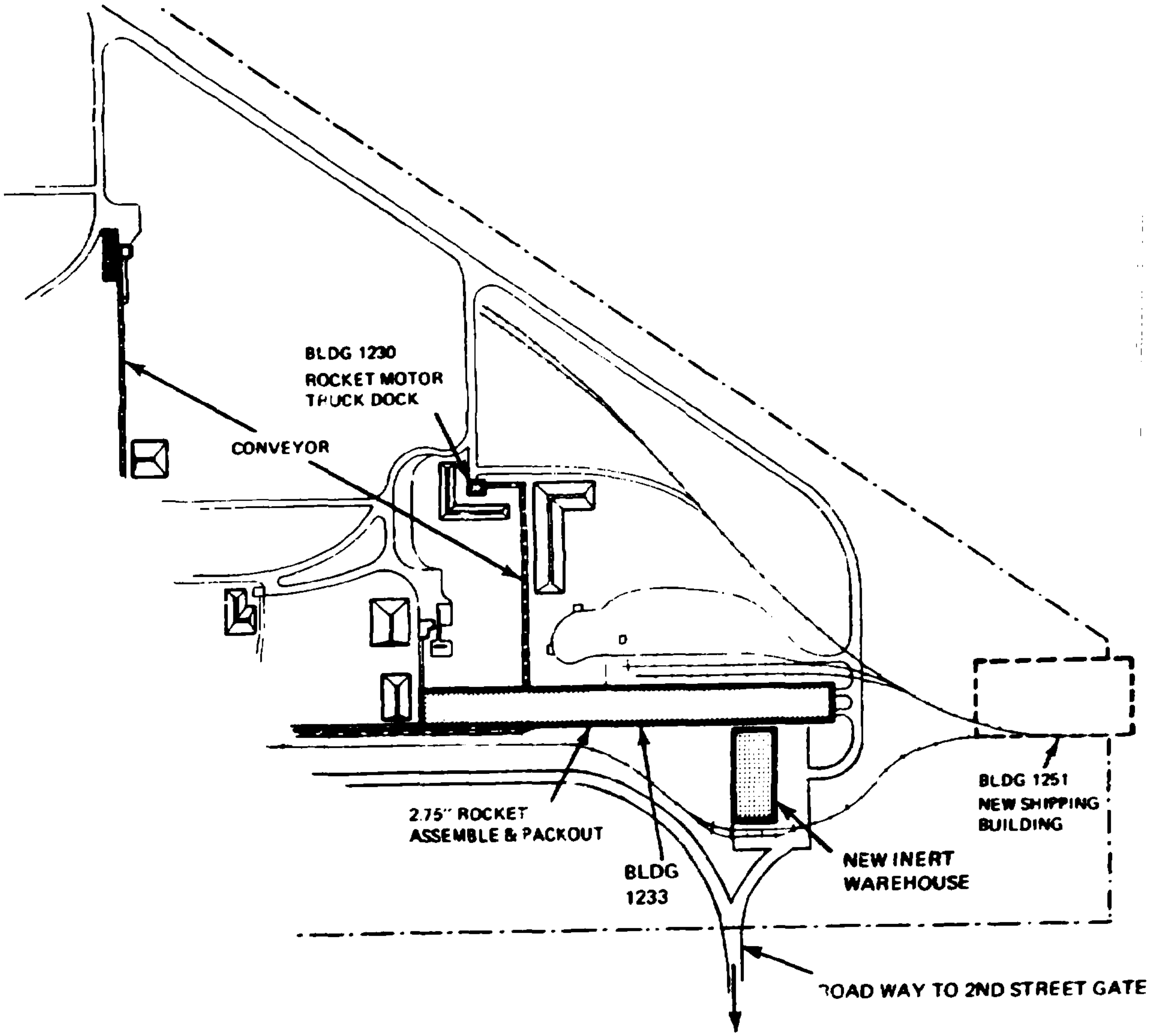
1. Rocket 2.75" XM229 W/F 423, 429
2. Rocket 2.75" M151 W/F 423, 429, 427

Present Operation

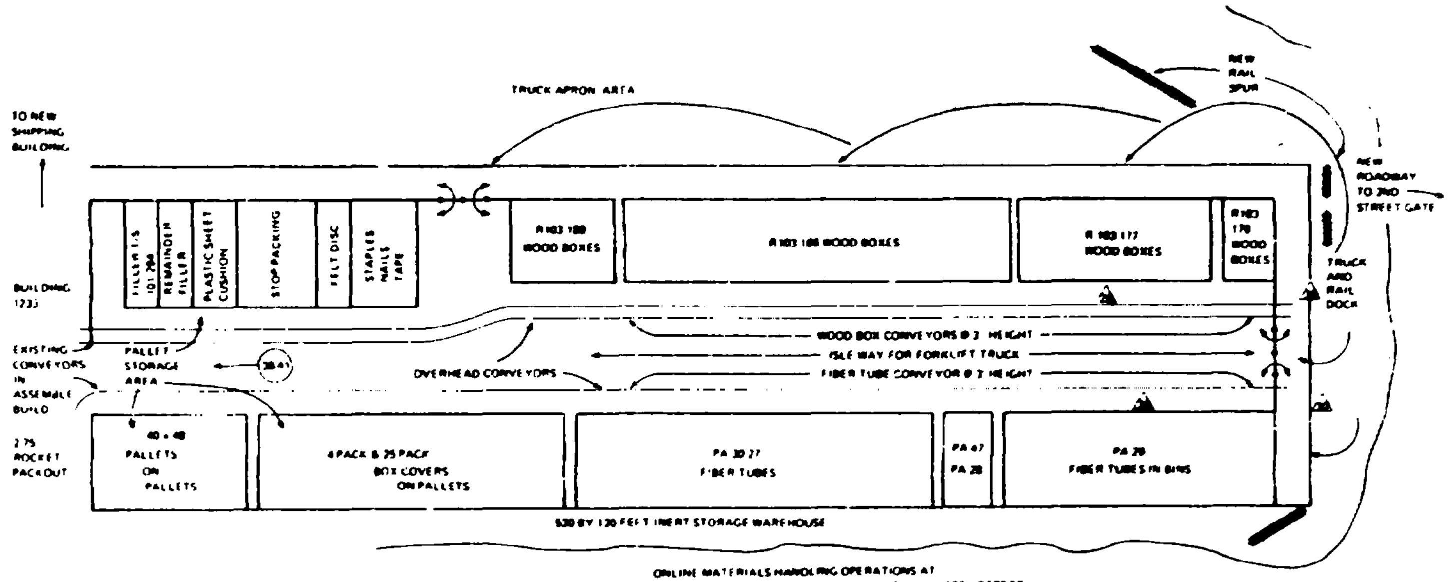
Composition "B" is currently shipped by the vendor to the LAAP by both truck and rail transportation. Rail shipments are transferred across a transfer dock to truck by the LAAP. All Composition "B" is then stored in Explosive Yard "L." Composition "B" is supplied to the 2.75" assembly line on a daily basis by plant trucks. Exhibit IV-3-1, Page IV-3-8 of the Phase I LAAP Report identifies the off-line materials handling activities as well as the cost incurred for the present off-line operation.

Proposed Operation

In order to eliminate double handling of explosives, a new explosive magazine should be constructed at Line "D" which would accept both truck and rail shipments of Composition "B" directly from the vendor. The new magazine should have an explosives capacity for a 5-day supply equal to 258,000 pounds of Composition "B" at the monthly mobilization production rate of 86,000 XM229 and 276,000 M151 2.75" rockets. The proposed new operation would eliminate ninety percent



Proposed Approximate Location of New On-Line Warehouse for Inert Packing Materials

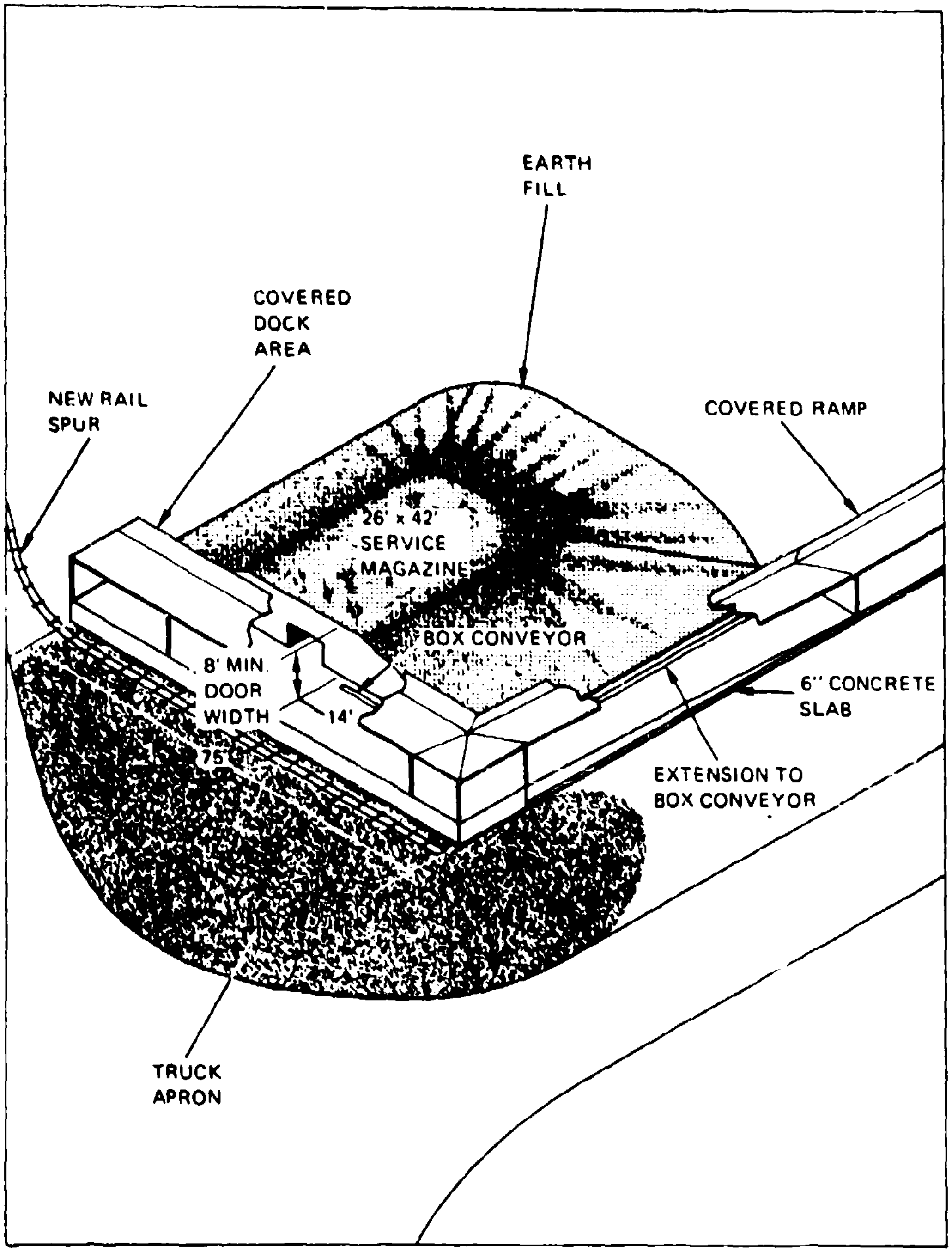


ONLINE MATERIALS HANDLING OPERATIONS AT LINE D FOR 2.75 ROCKET (SEE EXHIBIT IV-5 PHASE I REPORT)

OPERATION NODE	MATERIAL DESCRIPTION	OPERATION PERFORMED		MODE CONVEYANCE	NUMBER END ITEMS
		BUILDING	ACTIVITY		
30	FIBER CONTAINERS	NEW INERT STORAGE	CUT STRAPS LOAD FIBER TUBE ON CONVEYOR	NA	7
36	WOOD BOXES 4-25 PACK	NEW INERT STORAGE	PLACE WOOD BOXES ON CONVEYOR	NA	4 25
38 41	FILLER PALLETS BOX TOPS 4/25 PACK INERT MATERIALS	NEW INERT STORAGE	SUPPLY TO ASSEMBLE AS REQUIRED	FORKLIFT	VARIES

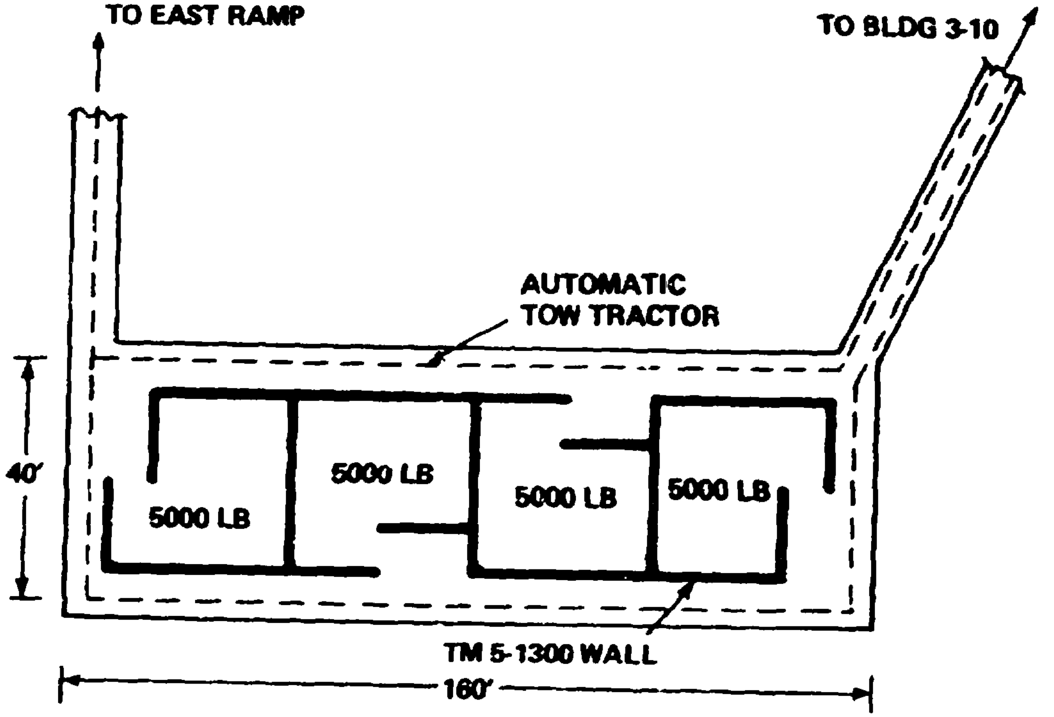
NOTE NO CHANGE NUMBER SUPPLY OPERATIONS ASSIGNED THESE TASKS SEE TABLE IV 6 PHASE I REPORT

Proposed Floor Plan and Operation for New Inert Packing Material Warehouse

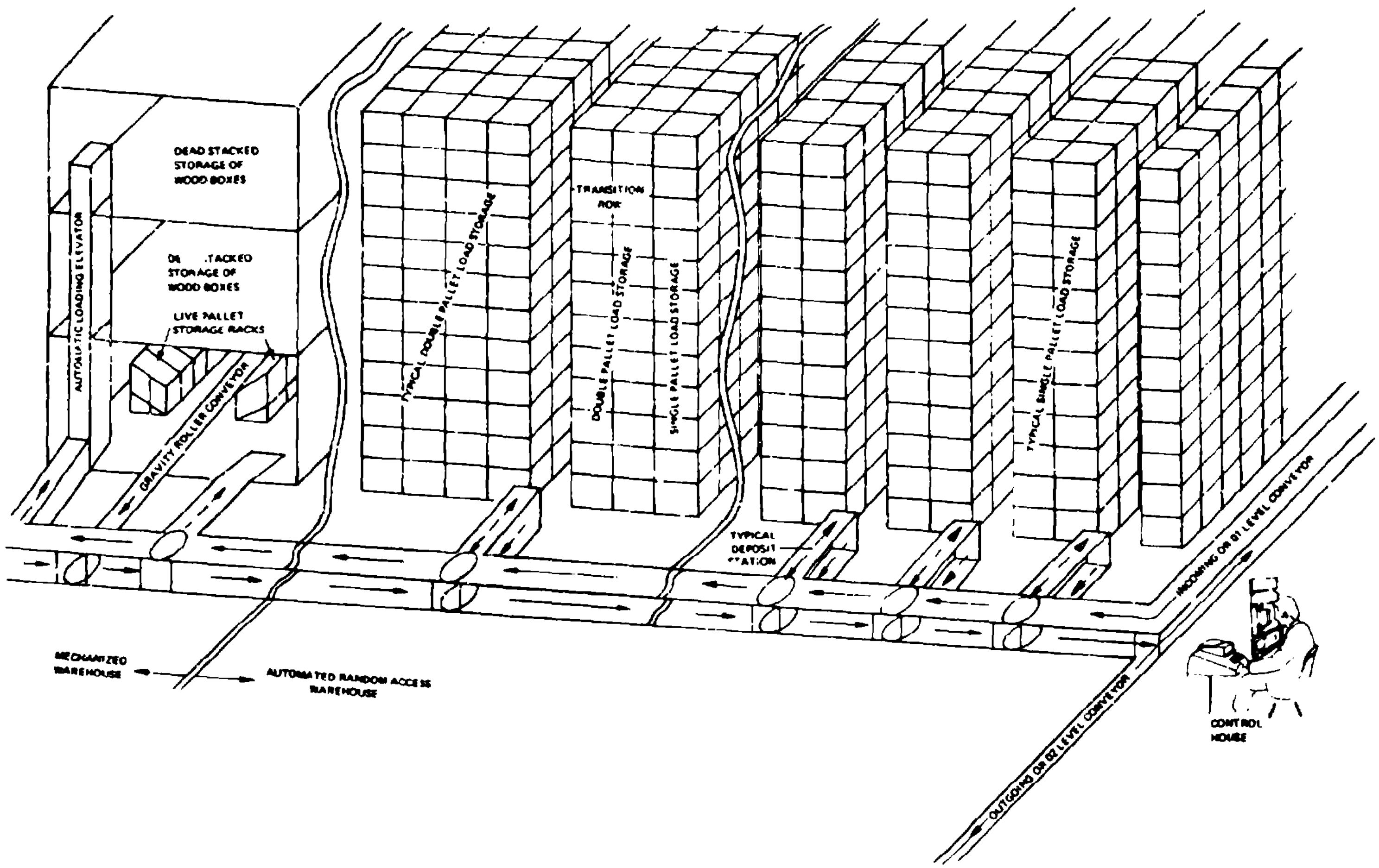


Conceptual Design of New Explosive Magazine, Louisiana Line D

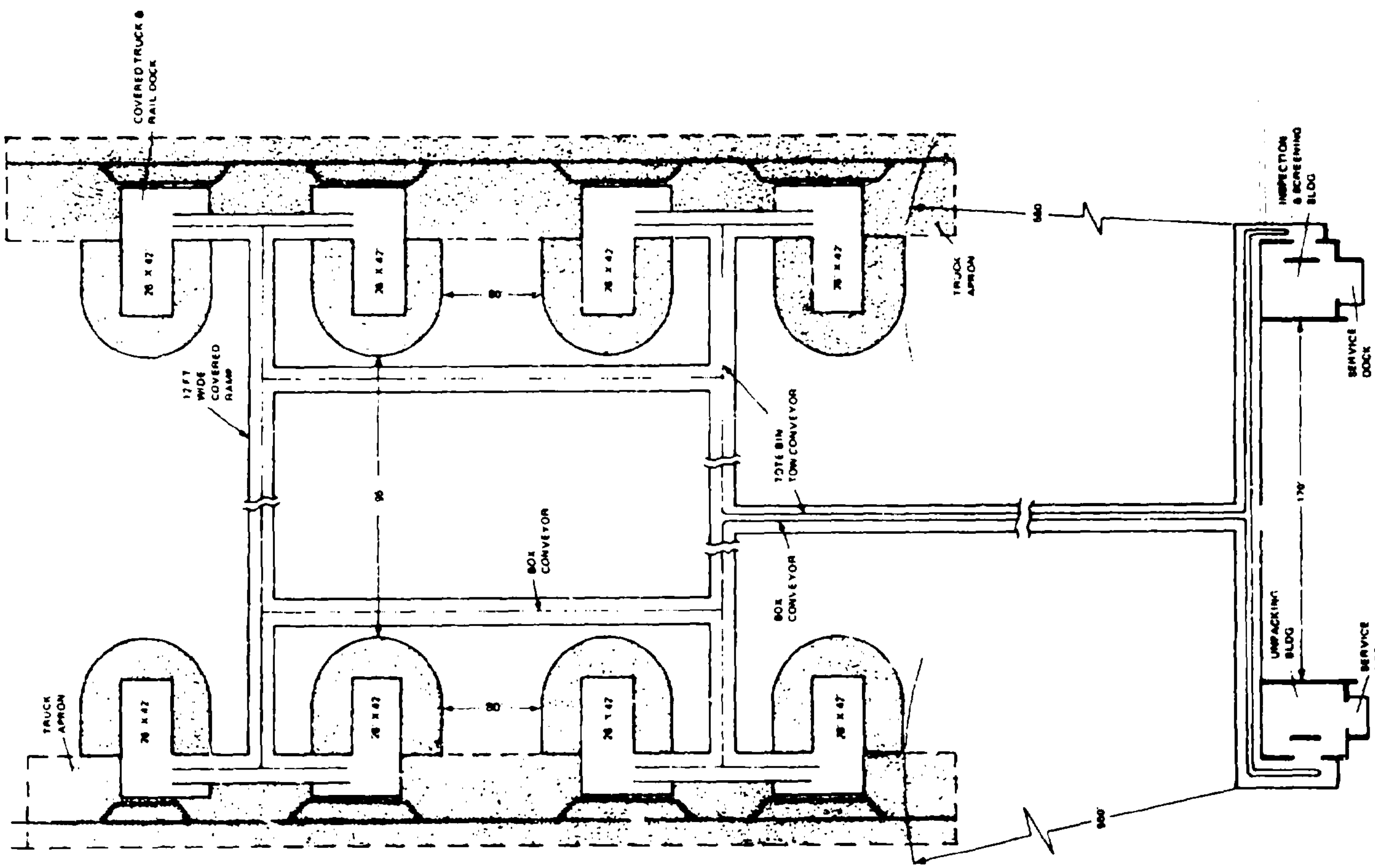
IN-PROCESS SUBASSEMBLY STORAGE ON LINE-3



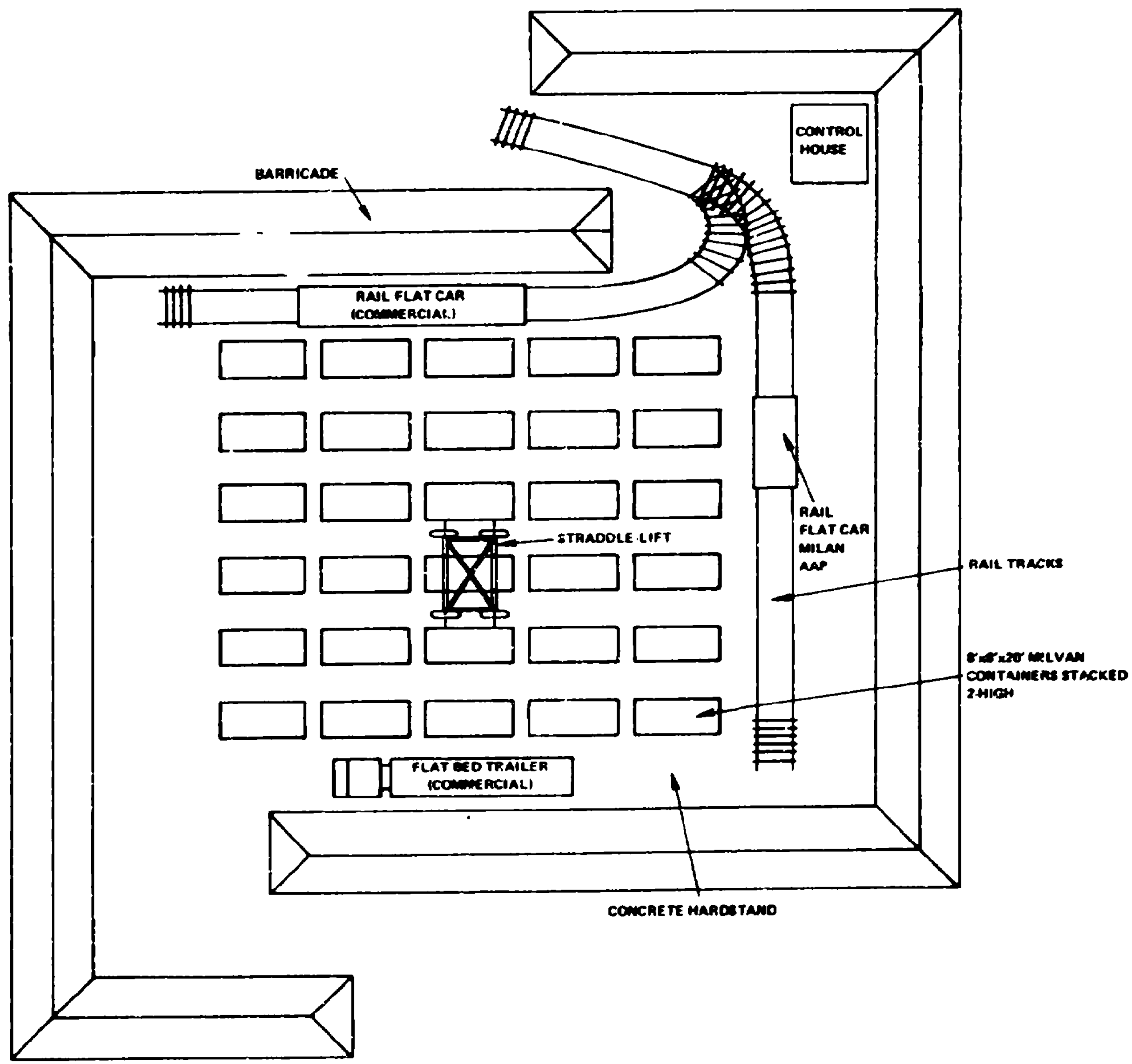
CENTRALIZED, AUTOMATED AND MECHANIZED WAREHOUSE



CENTRALIZED BULK EXPLOSIVES MAGAZINE FACILITY

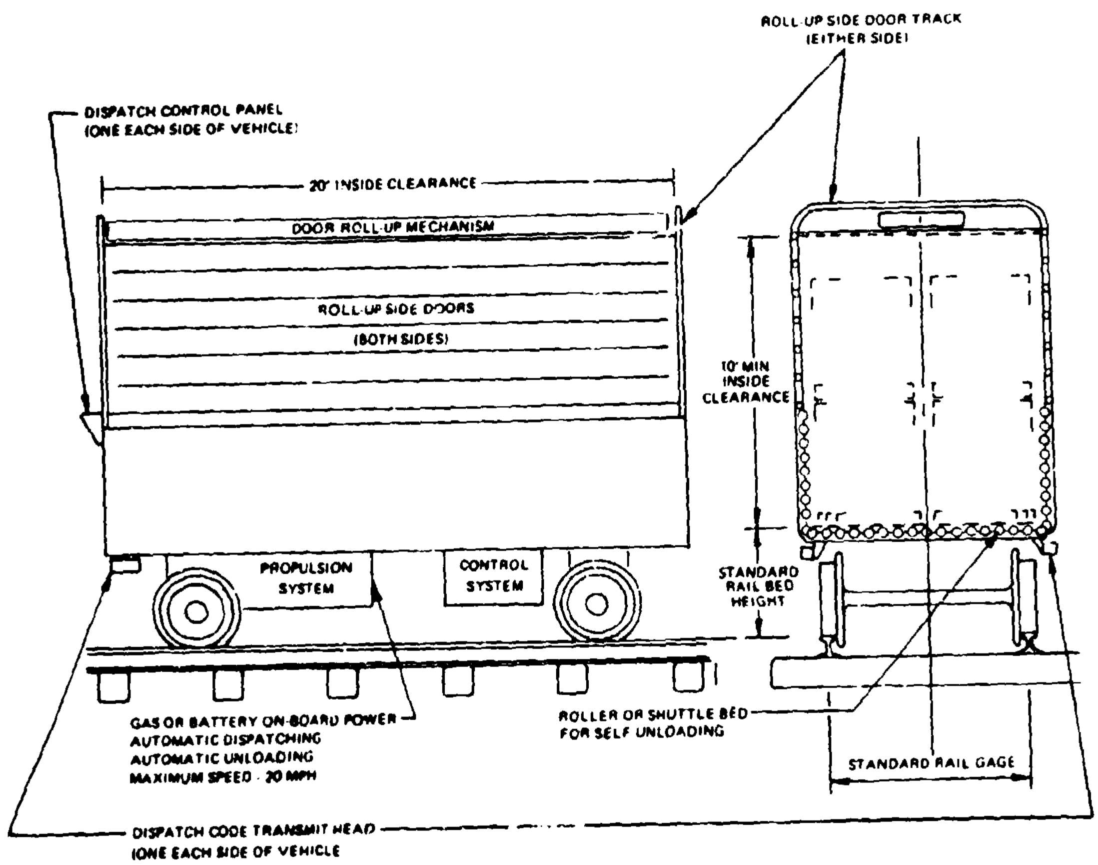


CONCEPTUAL LAYOUT OF MILVAN HOLDING YARD FOR SHORT TERM STORAGE OF FINISHED AMMUNITION 250,000 lb EXPLOSIVE LIMIT

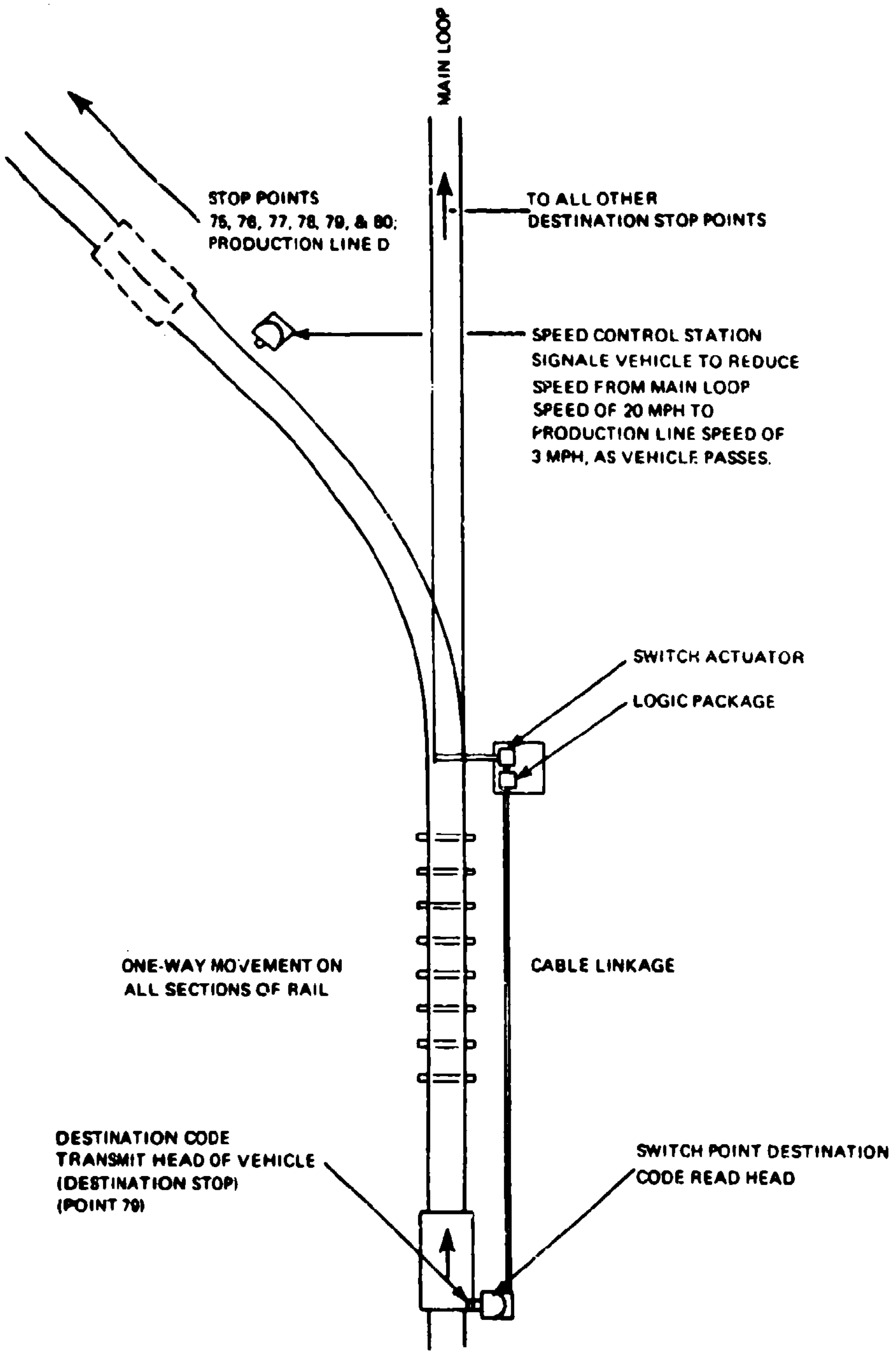


PROPOSED CONCEPT FOR AUTOMATED RAIL DISTRIBUTION VEHICLE

MAXIMUM CAPACITY - 40,000 LBS
- 10 PALLETS (UNSTACKED)
- 20 PALLETS (DOUBLE STACKED)



AUTOMATED SWITCHING CONCEPT



RECOMMENDED TOTAL PLANT
MATERIALS HANDLING MODERNIZATION SYSTEM
FOR MILAN AAP

- FOR INERT MATERIALS
  - BUILD A CENTRALIZED WAREHOUSE TO SERVE ALL LINES
- FOR BULK EXPLOSIVES AND PROPELLANTS
  - BUILD A CENTRALIZED RECEIVING, SCREENING & TEMPORARY STORAGE FACILITY
- AT THE PRODUCTION LINES
  - NEW FINISHED ITEM ON-LOAD FACILITIES
  - RAMPS, DOCKS, ROADS
  - STAGING AREAS
  - ON AND OFF LOAD POINTS
  - AUTOMATIC TOW TRACTORS
- FOR TRANSPORTATION OF MATERIALS
  - INSTALL SHUTTLE-BED SYSTEMS IN CONVENTIONAL RAIL & TRUCK VEHICLES*
- CONTINUE USE OF PRESENT METHODS FOR:
  - EXPLOSIVE COMPONENTS STORAGE
  - FINISHED AMMUNITION STORAGE*

· INVESTMENT REQUIRED:	$12,159,786
· ANNUAL SAVINGS:	3,256,476
· PAYBACK RATIO:	1.88

*FURTHER MODERNIZATION DEPENDENT UPON FUTURE DEVELOPMENTS OF AMMOVAN AND AUTOMATED RAIL CARS

ESKIMO II

Summary of Results and Damage Observations

Dr. T. A. Zaker
Department of Defense Explosives Safety Board

ESKIMO II was the second in a series of full-scale tests of earth-covered magazines sponsored by the Department of Defense Explosives Safety Board and conducted at the Naval Weapons Center, China Lake, California. Its primary purpose was to evaluate the protection afforded by magazine structures against communication of explosion when the headwall of one magazine faces the earth-covered side or rear of another. The test was executed on 22 May 1973. This paper summarizes selected preliminary results and damage observations.

Background

ESKIMO I, the first test in this series, was conducted in December 1971 to determine a safe, practicable minimum separation distance in face-on exposures of a U. S. Army standard steel-arch magazine.[1*] In ESKIMO I, explosion communication occurred to an acceptor igloo of this design at a distance of 1.25 $ft/lb^{1/3}$, but failed to occur at a distance of 2 $ft/lb^{1/3}$ to the rear of the donor. Further, the test revealed that increased safety and economy might be gained through improved design for closer balance in strength between the doors and headwall of the magazine. ESKIMO II, a full-scale proof test of other existing and modified door and headwall designs, utilized structures and facilities remaining from ESKIMO I, rebuilt as necessary to meet the aims of the test.

Objectives

ESKIMO II was designed to

- Evaluate the resistance of several door and headwall types in use by the U. S. military services, and of proposed modifications to existing designs, to blast loading simulating that from a magazine explosion.

- Obtain construction experience with, and test dynamically, a new noncircular steel-arch magazine structure.

- Evaluate the protection provided by distances specified by various authorities for public traffic routes.

- Investigate the hazards associated with large expanses of window glass used for architectural effect in commercial and institutional buildings.

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*Superscript numerals designate appended references.

Test Design

Five magazines were exposed face-on at the same distance from the explosion source, as shown in Figure 1. The magazine structures were earth-covered semicircular corrugated steel arches, except for a new type of noncircular steel arch built to a length of 80 ft in the northeast sector of the array. The igloo to the north was fitted with a U.S. Navy standard headwall having a two-leaf hinged door. That to the west had the same headwall and two-leaf hinged door construction tested in ESKIMO I, with an additional movable member spanning across the opening behind the door. The igloo to the south had a newly designed single-leaf sliding door which spanned the opening horizontally. For test control and comparison purposes, the igloo to the east had a door and headwall combination identical to that in ESKIMO I. The magazine in the northeast sector was fitted with a U.S. Army standard biparting two-leaf sliding door. Each of the magazines except the control igloo and that to the northeast contained an array of land mines as acceptor charges.

The explosion source consisted of 72 tritonal-filled 750-lb bombs in two triangular stacks, in base-to-base contact. This source was designed to produce an impulse load of 1100 psi-ms on the headwalls of the test magazines, a value expected from explosion of a full-size earth-covered magazine filled to capacity at the reduced rear-to-front separation distance of 2 $ft/lb^{1/3}$ determined in ESKIMO I. An initial peak reflected pressure of about 130 psi was expected. The source was surrounded by an earth mound barricade to intercept low-angle primary fragments from the bombs.

A number of highway vehicles and cubical wood-frame structures were located at various distances to the northwest and southwest from the source as shown in Figure 2. These locations correspond to U.S. and NATO public traffic route and inhabited building distances for an explosion source of 27,800 lb. Each cubicle was 9 ft on an edge. In each of the three arrays shown, the cubicles accommodated a sliding window pair, a projected window pair, and a type of window wall, all mounted in suitable commercially marketed suspensions. Foam plastic glass fragment traps were positioned behind the window openings. One additional window cubicle, as well as one of the vehicles, each contained an anthropomorphic dummy which was observed during the test by high-speed photography.

Instrumentation

Piezoelectric type pressure transducers were positioned in and near the headwalls of the test magazines. Accelerometers and linear motion transducers were mounted on the doors and headwalls of the structures. Self-recording mechanical pressure gages were placed in pairs at six stations near the distant targets.

The response of the magazine structures was observed by high-speed telephotography from three distant ground stations. Door motion was observed by means of a high-speed camera in the interior of each of the magazines.

After the test, selected previously cleared areas on the ground were searched for metal fragments in order to sample the fragment field from the explosion source. Residual displacements of the doors and headwalls of surviving magazines were measured.

Results

Measurements of blast loading made during the test show that the actual loadings on the magazine headwalls were significantly higher than the design level of 1100 psi-ms, and exhibited strong directional effects. As listed in Table 1, the impulse loads ranged from 1300 psi-ms with an initial reflected peak of about 200 psi on the west igloo, to 2200 psi-ms with an initial peak of 310 psi on the south igloo. Evidently directional effects which have been observed in the blast fields of elongated explosive sources[2,3] persist even in the case of compact but nonhemispherical charges such as the ESKIMO II source.

On the north igloo, the standard U.S. Navy headwall and door combination was tested at a blast loading about 60 percent greater than the design level. Despite this, the doors did not fail with sufficient violence to initiate acceptor explosives housed in the magazine.

On the igloo to the northeast, also subjected to blast loading 60 percent greater than the design level, the headwall and biparting sliding door combination for the U.S. Army Stradley magazine sustained modest damage to the headwall. The leaves of the door were severely deformed but remained in place. The relatively light-gage steel plates plug-welded to the inside faces of the door leaves were stripped off, but in most storage situations initiation of explosives by impact of these plates would be unlikely.

The igloo to the east was built with the headwall and door combination for the current standard steel-arch magazine, identical to the structures tested in ESKIMO I, the preceding event in this series. Though the structure was subjected to an impulse load nearly 40 percent greater than the test design level, the pattern of headwall cracking resembled that observed in the first test, with somewhat larger permanent deformations. The door leaves were driven off their hinges into the igloo and were considerably bent and distorted.

A comparison of deflection profiles taken at four elevations on the headwall of the east igloo and the south igloo of ESKIMO I is shown in Figure 3. It should be kept in mind that the impulse loading on the

latter structure was approximately 700 psi-ms, with an initial peak reflected pressure of about 75 psi, this impulse load being roughly half the corresponding level measured at the east igloo in ESKIMO II.

The igloo to the west was also of the same construction as that tested previously, but the doors were strengthened by adding a movable structural member which spanned across the opening behind the door. This igloo was subjected to an impulse load only slightly greater than the test design level, yet the headwall sustained significantly greater damage than its counterpart at the east position. The connections of the door reinforcing member failed where they were attached to the headwall. Acceptor explosive charges housed in the magazine ignited and burned. This result appears to rule out the prospect of simple structural modifications to upgrade existing magazines.

The newly designed single-leaf sliding door, in combination with the headwall of the standard steel arch magazine to the south in ESKIMO II, was subjected to an impulse load of twice the design level. The door sustained residual deflection measuring only about 10 in. at its bottom edge and, despite disastrous failure of the headwall on which it was mounted, did not cause initiation upon impact with acceptor explosives housed in the magazine. The result demonstrates a severe disparity in strength between the headwall and door of this test structure as built. Combined with the standard Stradley magazine headwall, however, the single-leaf door would probably provide a high degree of resistance to blast loading.

The newly designed oval steel arch igloo withstood quite well the blast loading to which it was subjected in ESKIMO II, sustaining residual deflections of the order of an inch at its crown. This warrants a planned major test involving lateral loading to complete the evaluation of the explosion resistance of this arch.

In contrast to the near-field effects, blast pressures and impulses at large distances from the source were uniformly lower than predictions based on a bare TNT hemisphere, as shown in Table 2. This behavior is also characteristic of elongated, rectangular explosive charges.[3]

All ten panes of glass in the four window cubicles at 1210 ft, the U.S. inhabited building distance for 27,800 lb of explosive, were broken and 323 glass fragments were captured in foamed plastic glass fragment traps positioned behind the window openings. Seven of eight panes in the three cubicles at 1700 ft, the NATO inhabited building distance, were broken and 102 fragments were found lodged in the glass traps. None of the eight panes broke at the 3400 ft location. Fragments recovered from the glass traps are being analyzed for weight and velocity distributions by established techniques correlating impact energy and pit volume in foamed plastic. Glass fragments cut three small (1/8-in. diameter) holes in the shirt worn by the dummy in one of the window cubicles at the nearest station, but no lacerations were found on the dummy.

Limited window glass breakage and dishing of sheet metal panels occurred in the automobiles at the 730-ft stations (the U.S. public highway distance) to the northwest and southwest from the source. The dummy in the driver's seat of a station wagon broadside to the explosion at the 730-ft northwest station, observed by means of high-speed motion picture photography during the test, suffered no injury from flying glass nor was it displaced appreciably from its seat in the car during the event. Automobiles at the 1130-ft station (the NATO public traffic route distance) sustained minor cracking of windows, while no observable damage occurred to the one vehicle positioned at 1700 ft.

Future Plans

The next step of this magazine separation and design program will be to test the oval arch igloo under lateral loading produced by an igloo explosion at the minimum side-to-side separation required by DoD standards. The test will be performed with a donor charge of 350,000 lb net explosive weight in an actual storage igloo. Additional acceptors will be situated around the close-in array to determine the effects of the explosion on headwalls at various distances and orientations. Also included will be a lighter weight, lower cost type of steel arch magazine as one of the test structures. This will provide valuable information on the relative importance of earth cover and arch strength in reducing the risk of explosion propagation between igloos separated by the minimum permitted distances. Window test cubicles and automobiles will be positioned at suitable distances for correlation with the results of ESKIMO II.

References

[1] F. H. Weals, "ESKIMO I Magazine Separation Test," NWC TP 5430, April 1973.

[2] J. Wisotski and W. Snyer, "Characteristics of Blast Waves Obtained from Cylindrical High Explosive Charges," DRI 2286, Denver Research Institute, November 1965.

[3] URS Systems Corporation, "High Explosive Equivalency Tests of Large Solid Propellant Motors," NWC TP 4643, September 1968.

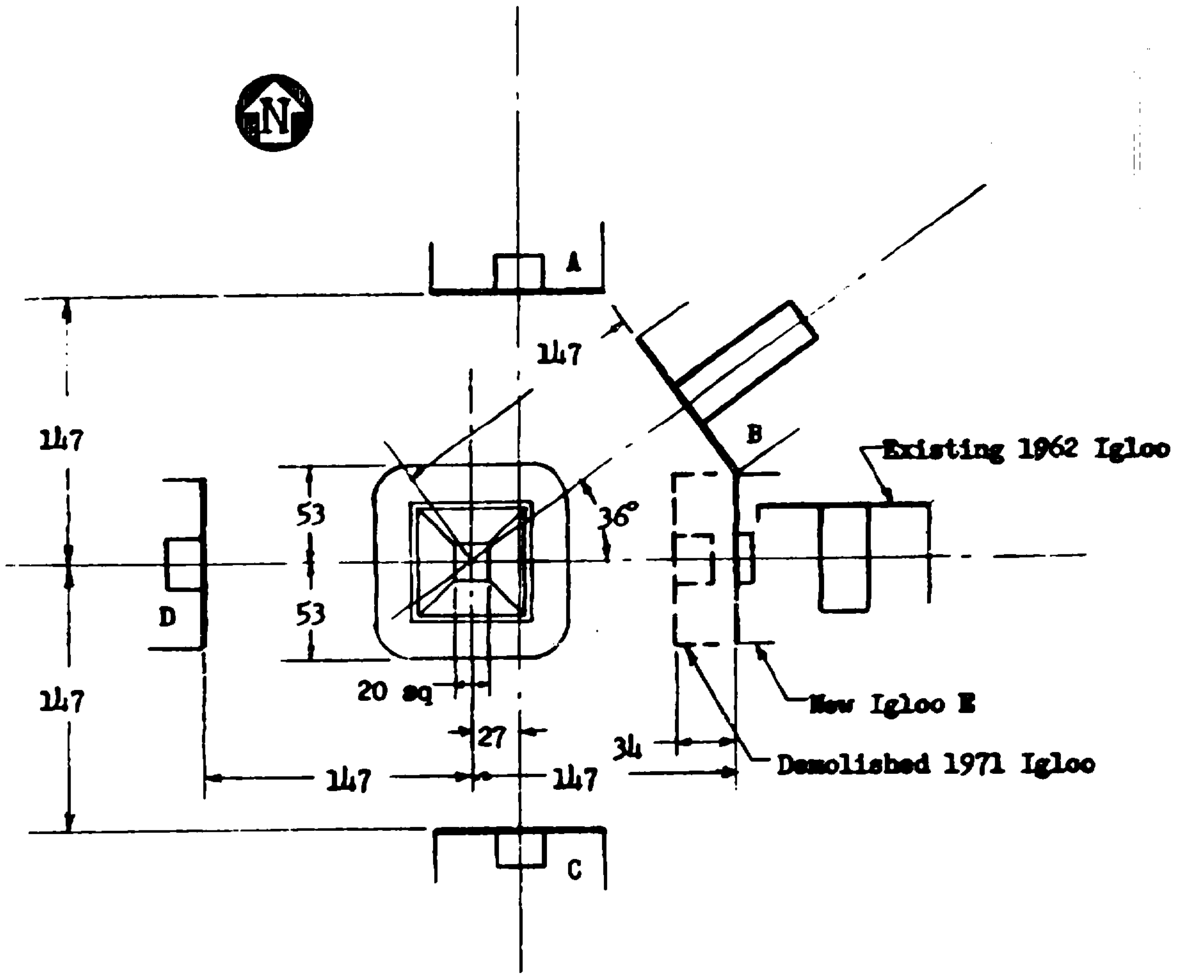

Figure 1 **ESKIMO II Test Area Layout**

Legend

Window Cube

European Sedan

US Sedan

US Station Wagon

Fuel Truck

Camera Station

Pressure Gage Pair

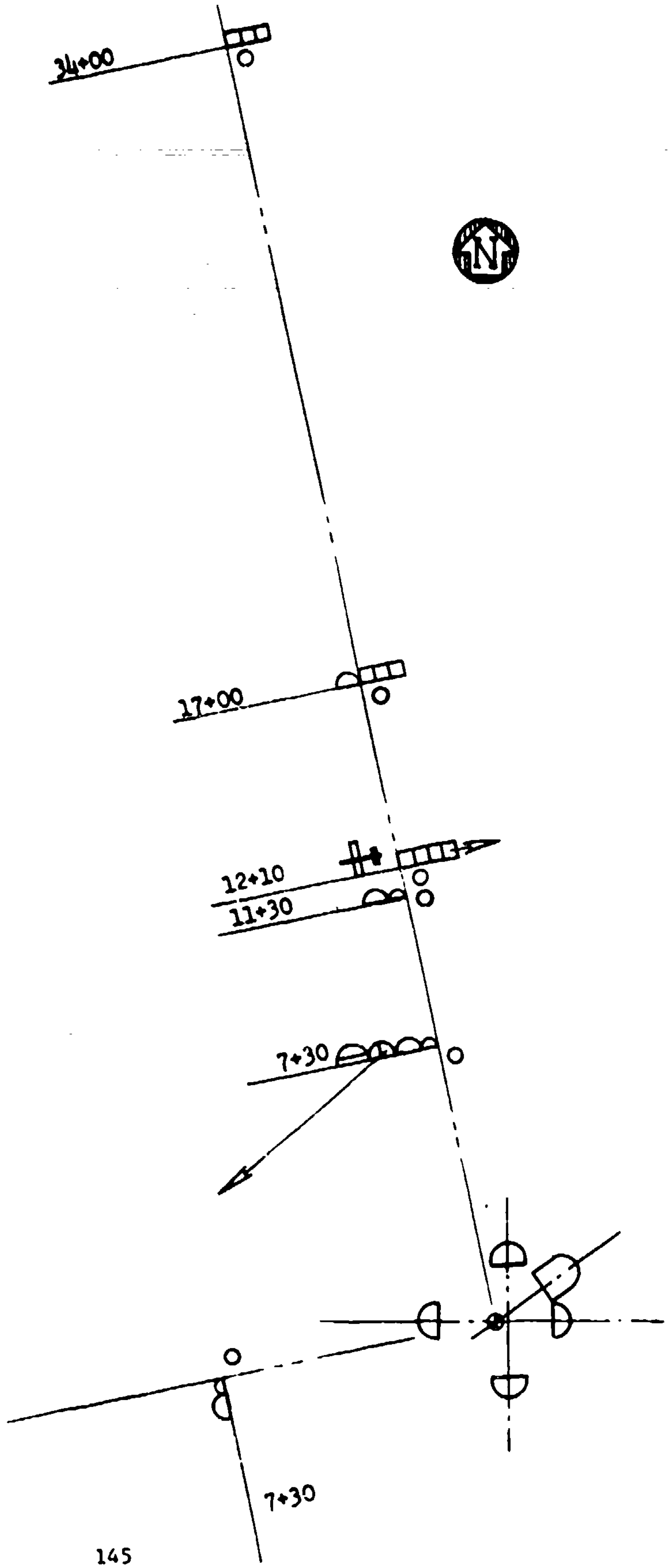

Figure 2

ESKIMO II Far Field Layout

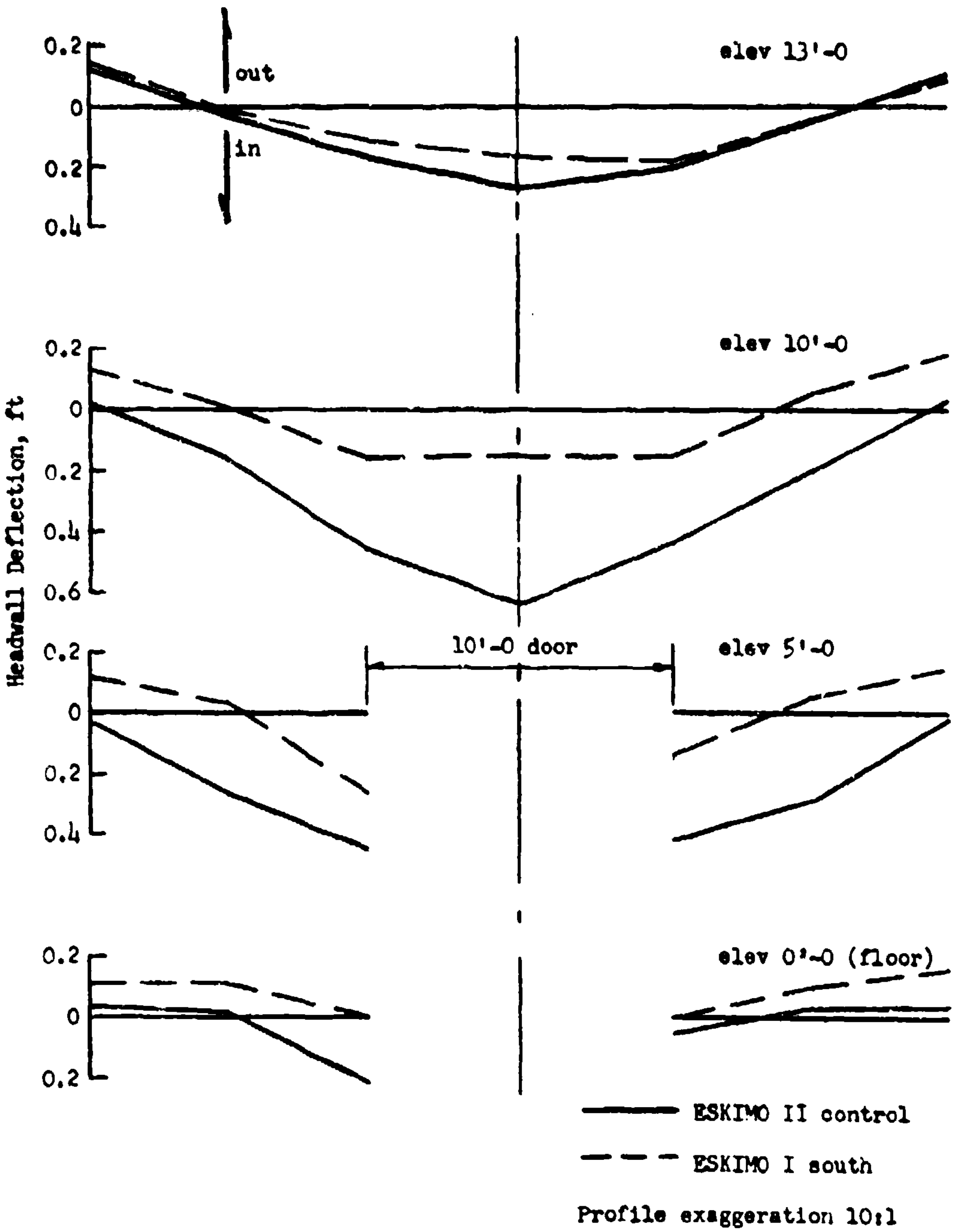

Figure 3 Headwall Deflection Profiles

Table 1

ESKIMO II

Preliminary Blast Impulse Data[a]

Igloo[b]	Pressure psi	Impulse psi-ms	Arrival Time ms
North	300	1780	39.6[c]
Northeast	252	1750	36.5
East	230	1510	35.8
South	310	2200	35.2
West, right	198	1240	36.3
West, left	205	1330	36.3
Design	130	1100	(d)

Notes

a. Source: Personal communication, F. H. Weals, 31 May 1973.
b. Gage to right of opening except as noted.
c. 153 ft from donor center to gage.
d. Immaterial; not predicted.

Table 2

ESKIMO II

Far-Field Blast Measurements[a]

Distance ft	Pressure[b] psi	Impulse[c] psi-ms	Pressure Predicted[d] psi
730	1.41	54.4	2.4
	1.05	50.7	
	1.01	47.9	
1130	0.71	31.8	1.3
	0.64	31.8	
1210	0.55	29.8	1.2
	0.49	27.9	
1700	0.38	22.3	0.75
	0.41	24.3	
3400	0.23	14.0	0.29
	0.17	12.7	

Notes

a. Source: Personal communication, C. H. Wilson, 12 June 1973.
b. TNT equivalent based on pressure: 7500 lb.
c. TNT equivalent based on impulse: 10,000 lb.
d. From TNT hemisphere with W = 27,800 lb.

LOADING PREDICTIONS FOR ESKIMO II

W. M. Baity
Balli-tic Research Laboratories
Aberdeen Proving Ground, Md.

ABSTRACT

The Ballistic Research Laboratories responded to an informal request by the Department of Defense Explosives Safety Board to determine the charge weight to be used in the Eskimo II test that would generate a 30 psi overpressure and yield a 1100 psi-millisecond impulse at a specific position on the headwall of an earth-covered steel arch igloo magazine located at a ground range of 147 feet.

A set of predictions was derived using the BRL computer program SLOFF. This program predicts the loading at any position on a rectangular surface oriented normal to the direction of travel of a plane shock wave. The geometry of this rectangular surface determines the sequence of rarefactions as seen at a point on the surface, hence, the program was modified to examine the magazine headwall polygon at a single position. The inputs simulated hemispherical TNT charge yields of $W^{1/3}$ equaling 21.5, 22.9 and 24.7 at ground ranges such that the side-on pressure was 20, 25, 30 and 40 psi. Evaluations were made using overpressure decay rates derived by both Brode and Kingery.

The charge source was restricted to 750-lb M117 bombs. Based on hemispherical TNT surface burst studies, the effective yield of M117 bombs and the loading prediction of SLOFF, recommendations for a 72 M117 bomb source were made. The predicted side-on pressure was 38 psi with a 1100 psi-millisecond impulse at the specified headwall position. Since shape precluded hemispherical stacking, the alternative of triangular stacking was suggested.

INTRODUCTION

The Ballistic Research Laboratories (BRL) responded to an informal request by the Department of Defense Explosives Safety Board (DDESB) to determine the charge weight to be used in the Eskimo II[1*] test. This experiment was designed to obtain blast loading and response data on full scale storage igloos of varied headwall and door construction. To make effective use of the capital assets remaining after the completion of Eskimo I test[2], it was decided to centrally locate the charge (Slide 1)[**] such that the three remaining storage igloo headwalls and the two to be added would be subjected to similar loading. Results from Eskimo I and previous model studies indicated that a charge which would generate a 30 psi overpressure and yield an 1100 psi-millisecond impulse at a specific position on the headwall was desirable. (Slide 2) The DODESB final specifications were that the ground range would be 147 feet and that the impulse should be 1100 psi-millisecond with side-on pressure being the variable parameter.

A set of predictions was derived using the BRL computer program SLOFF[***]. The inputs to the program included positive phase overpressures ranging from 20 to 40 psi maximum side-on pressure with the decay rate and duration corresponding to that expected from hemispherical TNT charges at specific ground ranges. The output, expected impulse at the

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[*] Superscript numbers denote references listed on page 157.

[**] Slides are in Appendix A.

[***] Computer program - Shock Loading On Front Face.

designated position on the headwall, was extrapolated to provide the proper impulse at the selected ground range which in turn indicated the TNT equivalent charge to be used.

BACKGROUND OF SLOFF

A set of experiments was conducted at the BRL Shock Tube Facility to study the diffraction loading phase on the front surface of a structure subjected to blast overpressures. The presence of reflected pressure associated with the initial phase of the air shock overpressure causes net loads to be exerted on the surface in the direction of travel of the shock wave. The average front surface loading during the diffraction phase has been approximated as a first degree equation decaying from reflected pressure, at the time of arrival of the shock wave, to stagnation pressure at clearing time[3]. This, along with a weighting system, allowed a structural study under certain loading conditions. Failure of walls subjected to blast loading at other test laboratories indicated the need of a better description of the loading history. Shock tube tests on several models at BRL provided the basis for the computer program SLOFF designed to predict pressure and force associated with some point or area on the front surface as a function of time.

SLOFF is based on empirically derived equations and designed to predict the loading on any rectangular surface oriented normal to the direction of travel of a plane shock wave. Subroutines provide plotted and tabulated pressure, force or impulse predictions using either peaked wave or step functions inputs. In addition, there are variations

of the original computer program that provide the options of three dimensional pressure mapping at specific times of interest, as well as the plotting and tabulation of average pressure predictions associated with a particular area. The program was written for the BRLESC II computer using FORTRAN IV as the language.

DEVELOPMENT OF SLOFF

The preliminary experimentation was conducted in a 4 × 15 inch shock tube using a two dimensional model. Pressure-time measurements were made with ST-2 piezo-electric pressure transducers appropriately positioned on the model. Prediction technique derived from these data were tested against three dimensional model data generated by a series of shots in the 24 inch shock tube. In addition, a larger set of models was used in a 5 1/2 foot diameter shock tube and the data from all tests combined in the derivation of the pressure prediction equations. All shock wave inputs were step functions so that the side-on pressure remained relatively constant during the diffraction loading phase. Peaked wave input data was obtained from previously fired full scale field tests. Current tests series data are being incorporated with the original work in order to better define the instantaneous pressure at any point on the surface.

The analog data was digitized and normalized with respect to reflected pressure and clearing time (Slide 3). A least square fitting was made to determine the pressure P_n associated with the time of arrival of the "n"th rarefaction (Slide 4). The results were tested on the more general three dimensional case and all data were used to

refine the equations for the pressure P_n through the arrival of the first four rarefactions (Slides 5, 6 and 7).

The prediction equation derived for the overpressure P at time t for a single point on the front surface during the diffraction phase is of the following form after the arrival of the first rarefaction wave (Slide 8):

$$P = P_n \left(t / T_n \right)^{M_n} \quad \text{at} \quad T_n < t < T_{n+1} < T_5$$

and where n = 1, 2, 3, and 4

P_1 = Reflected pressure

P_5 = Stagnation pressure

P_{n+1} = P at $t = T_{n+1}$

T_n = Time of arrival of the "n"th rarefaction wave

T_5 = Clearing time = $3h'/A_5$

$M_n = \mathrm{Log}_{10}(P_{n+1}/P_n)/\mathrm{Log}_{10}(T_{n+1}/T_n)$

h' = Clearing height = height of surface or one-half the width, whichever is least

A_5 = Speed of sound in the reflected region.

Prior to the arrival of the first rarefaction, the instantaneous pressure at a given point equals the reflected pressure P_1. The pressure P may be expected to diminish at a rate dependent on subsequent rarefaction arrivals; and at clearing time approaches stagnation pressure. To handle peaked wave inputs where the side-on pressure decays exponentially, the program calculates reflected pressure, stagnation pressure, and the speed of sound in the reflected region as a function of side-on pressure. To facilitate the duplication of actual

blast inputs, the computer program offers the option of inserting an equation of the decay of the side-on pressure as a function of time. Reasonable correlation was obtained when full scale field tests data were examined using this technique (Slide 9).

Now that the single point pressure-time curves could be predicted, this method was extended to any point on the front surface (Slides 10, 11 and 12). By positioning a point in a small area, a good approximation of force and impulse as functions of time could be associated with the area. Tabular print out options of normalized or real time and pressure as well as force and impulse in time increments may be chosen by the programmer.

APPLICATION OF SLOFF TO ESKIMO II

One of the limitations of SLOFF is that the program only evaluates a rectangular surface that is perpendicular to the ground and normal to the direction of travel of a plane shock wave. Modifications were made so that the program could evaluate the single point of interest on the magazine headwall polygon. The program can evaluate the effect of rectangular openings in the front surface but in this series the doors were considered as capable of withstanding the loading. It should be mentioned that the program makes no provision to handle reflections or compression waves generated by surface irregularities or objects in proximity to the area of interest.

Input parameters included the maximum side-on pressure and positive phase duration (Slide 13). Three hemispherical TNT charge weights[4] of 10,000 lb, 12,000 lb and 15,000 lb were choosen for evaluation at four

ground ranges each, corresponding to maximum side-on pressures of 20, 25, 30 and 40 psi. Appropriate durations were associated with these twelve conditions and an impulse was calculated for each. The first evaluation used an overpressure input function that decayed from side-on pressure to stagnation pressure exponentially using equations suggested by Brode[5] and a second evaluation was made using the decay rate described by Kingery[4].

Subsequent examination of these output data demonstrated that cube root scaling could be used over the range in the determination of impulse at the gage position on the headwall. The DDESB had made final decisions on magazine positions for the Eskimo II test and established a ground range of 147 feet common to the center of all magazine headwalls (Slide 14). Extrapolation of the data at this ground range indicated that a 24,000 lb hemispherically shaped TNT charge would provide the desired 1100 psi-millisecond impulse at the specified gage position. The predicted side-on pressure was 38 psi and the positive phase duration was 45.5 milliseconds.

COMMENTS

Recommendations of a relatively clean predictable source such as ammonium nitrate/fuel oil was made, but because of other considerations the source was restricted to 750 lb M117 bombs surrounded by an earthen revetment. The effective yield of the M117 bomb[6] suggested a nominal 72 bombs as equivalent to the recommended TNT charge. Since bomb shape precluded hemispherical stacking, the alternative of triangular stacking was suggested. Even though this arrangement offered a number of

uncertainties - such as correspondence in effective yield, edge effects from the stacking, correspondence in overpressure wave shape, coalescence of multiple shocks and their expansion over the revetment into a plain wave in the near field - it was anticipated that a good pressure-time history would be recorded and that this could be used as an input to a modified SLOFF program that would evaluate the average loading on the magazine doors. Correlation of test measurements and predictions will be made after the test data has been evaluated.

REFERENCES

1. Perkins, R. G., "Eskimo I", Fourteenth Annual Explosives Safety Seminar Minutes, Department of Defense Explosive Safety Board, November 1972.

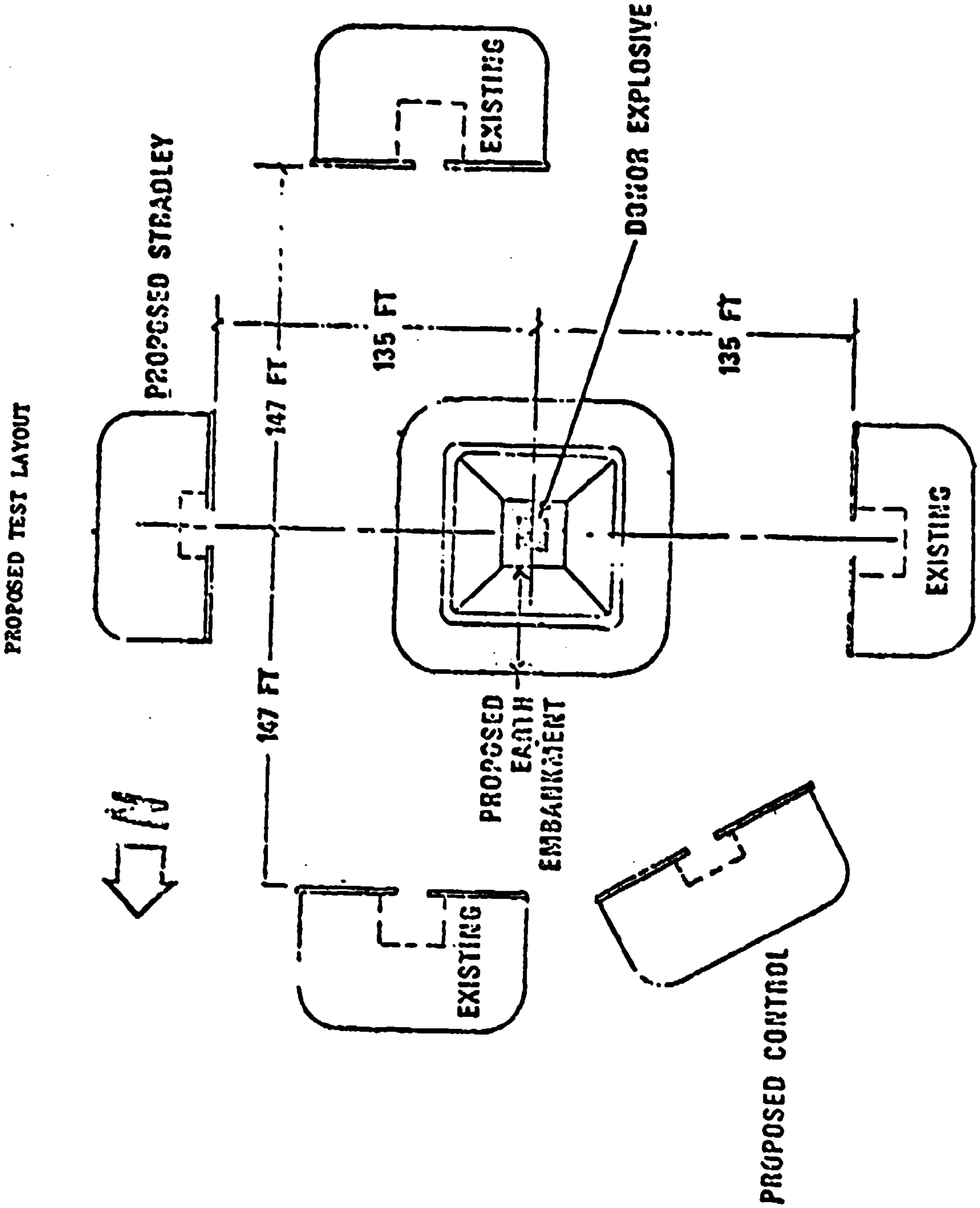
2. Warren, T. W., et al., "Interior Blast Pressures of Acceptor Magazines: Eskimo I," Fourteenth Annual Explosives Safety Seminar Minutes, Department of Defense Explosive Safety Board, November 1972.

3. "Design of Structures to Resist the Effects of Atomic Weapons", Headquarters, Department of the Army, TM 5-856, November 1960.

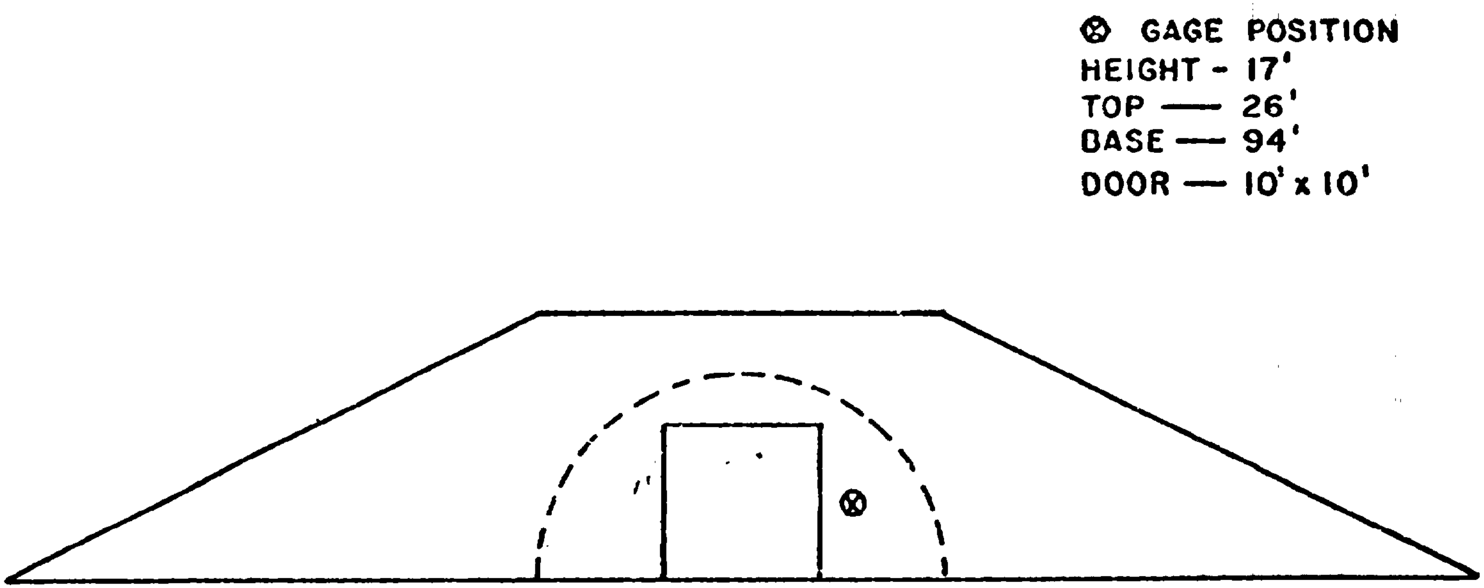
4. Kingery, C. N., et al., "Airblast Overpressure Versus Time Histories (Nuclear and TNT Surface Bursts)", Ballistic Research Laboratories Report No. 1638, March 1973.

5. Brode, H. L., "A Review of Nuclear Explosion Phenomena Pertinent to Protective Construction," Rand Document No. R-425-PR, Rand Corp., Los Angeles, California, May 1964.

6. Fugelso, L. E., et. al., "A Computation Aid for Estimating Blast Damage from Accidental Detonation of Stored Munitions," Fourteenth Annual Explosives Safety Seminar Minutes, Department of Defense Explosive Safety Board, November 1972.

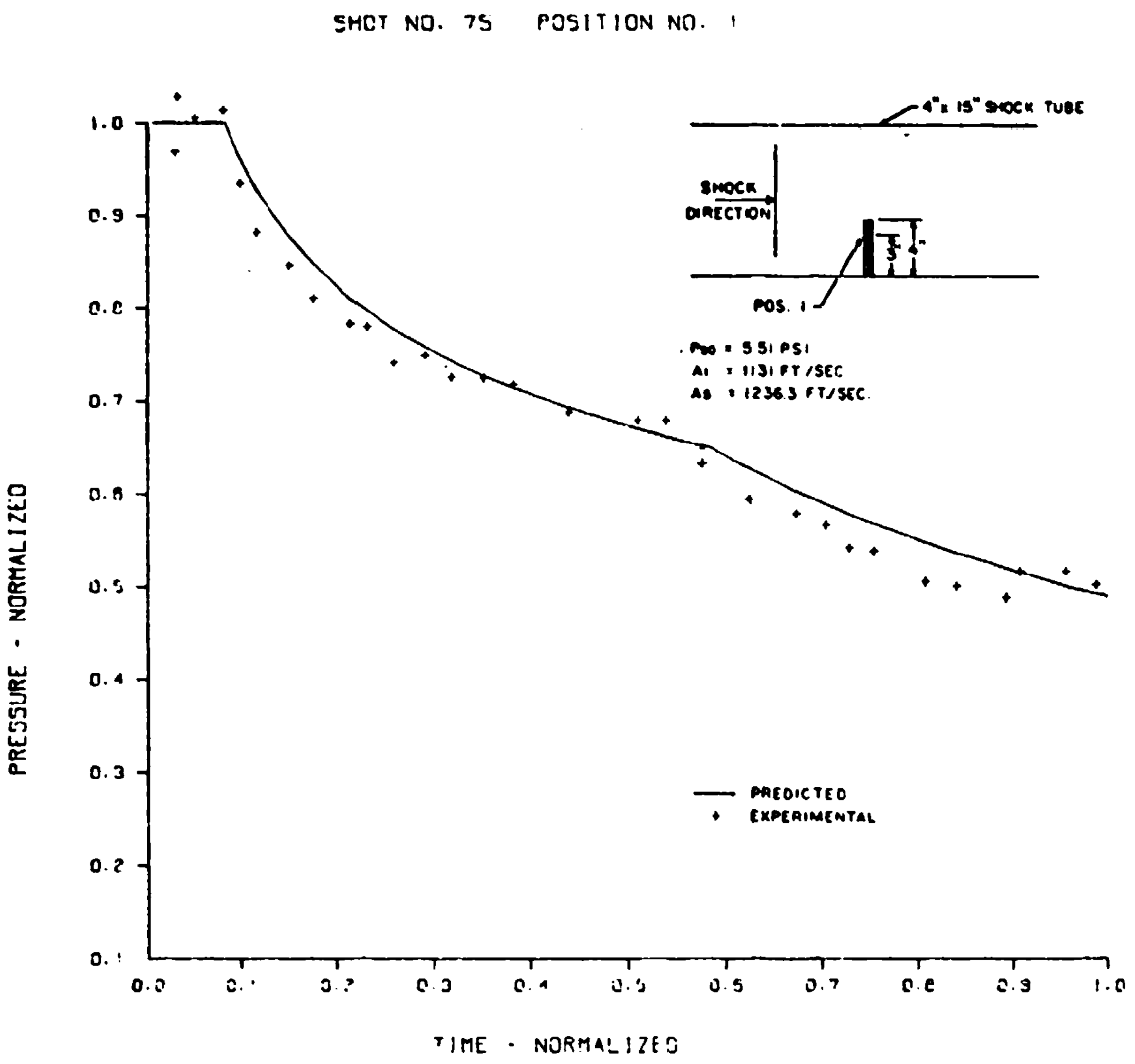

PROPOSED TEST LAYOUT
PROPOSED STRADLEY
EXISTING
DONOR EXPLOSIVE
147 FT
135 FT
135 FT
EXISTING
147 FT
PROPOSED EARTH EMBANKMENT
N
EXISTING
PROPOSED CONTROL

Slide 1

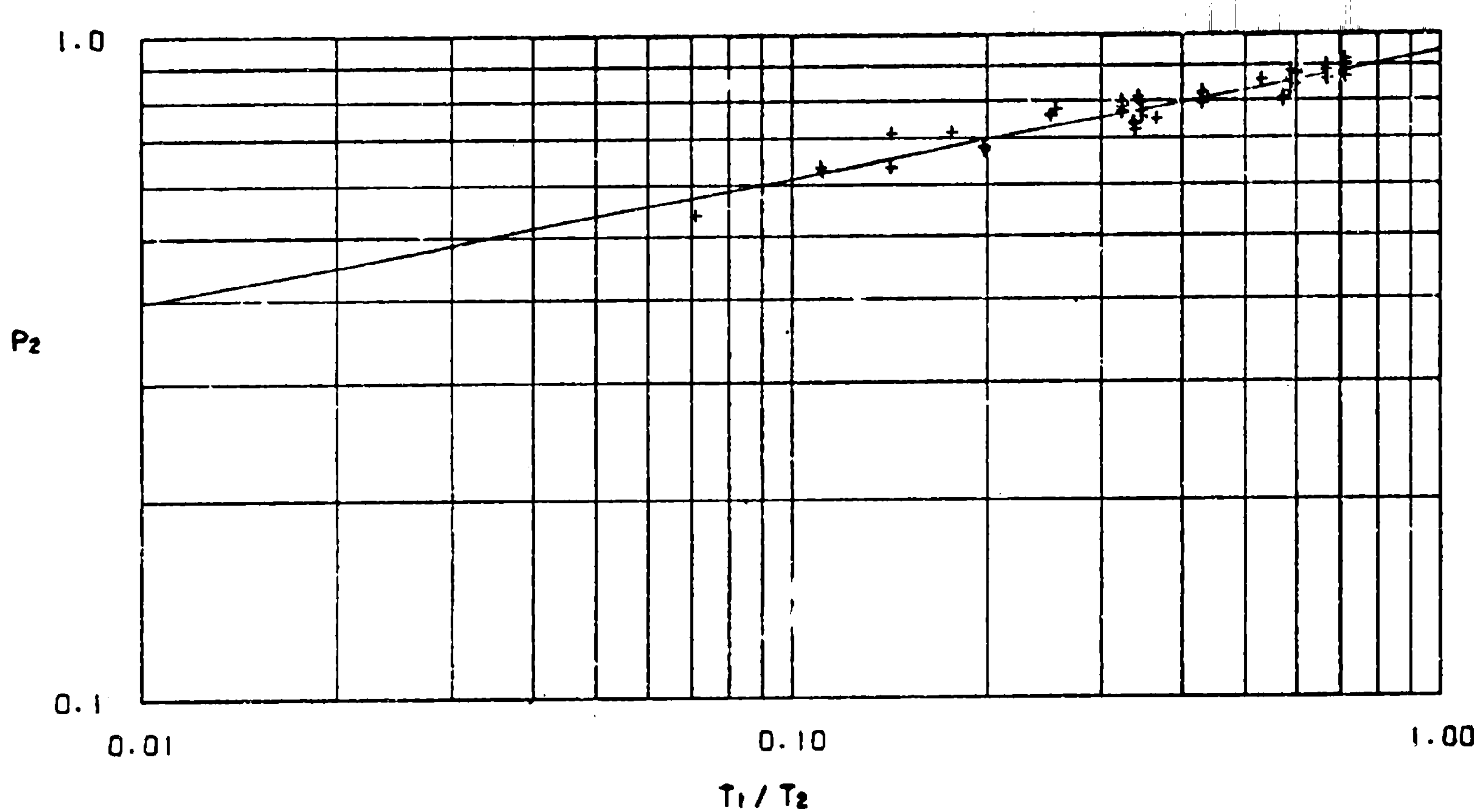


FRONT FACE — IGLOO HEADWALL

Slide 2

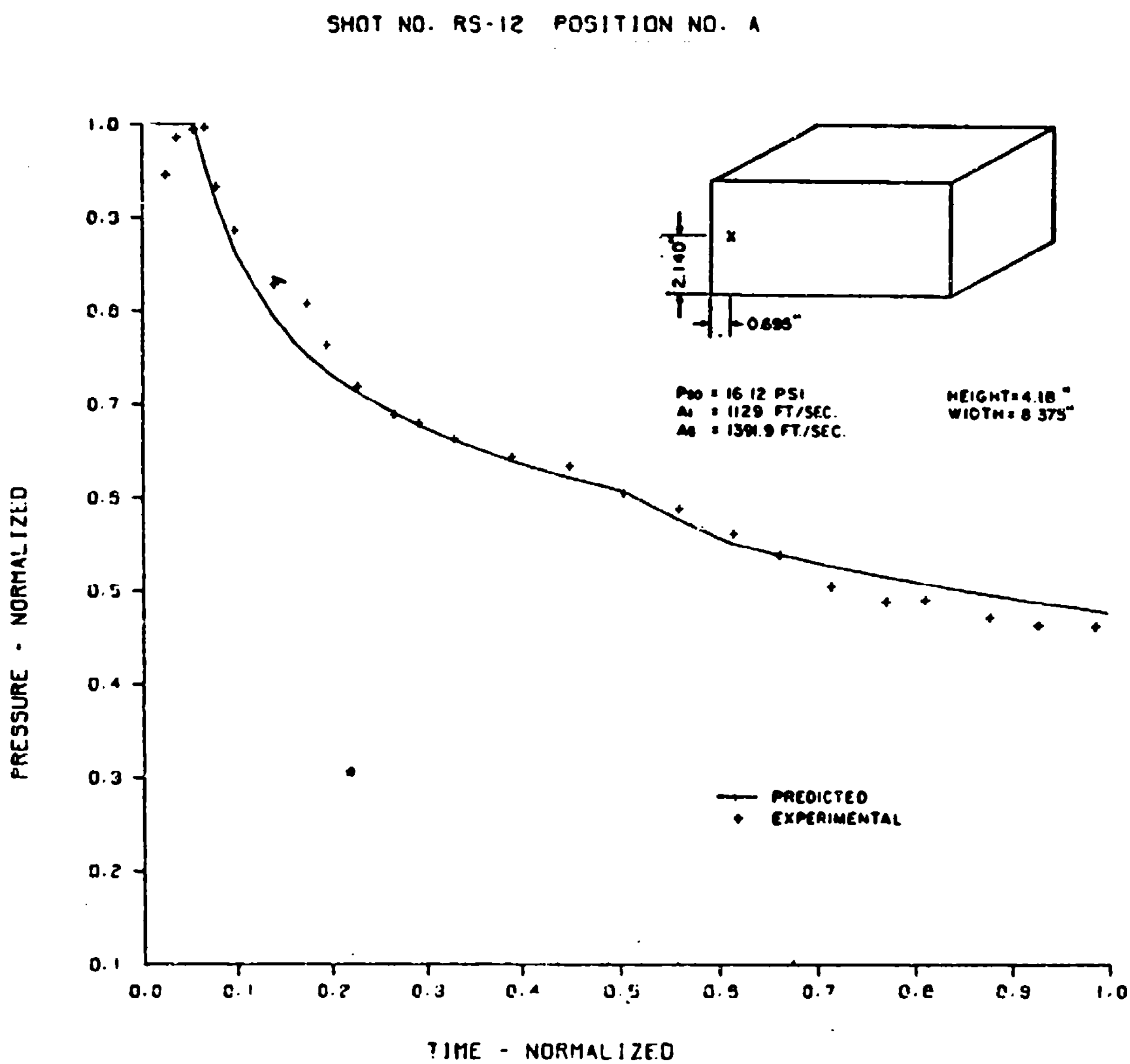

SHOT NO. 75 POSITION NO. 1
4" x 15" SHOCK TUBE
SHOCK DIRECTION
POS. 1
Pso = 5.51 PSI
A1 = 1131 FT/SEC
As = 1236.3 FT/SEC
PREDICTED
EXPERIMENTAL
PRESSURE - NORMALIZED
TIME - NORMALIZED

Slide 3



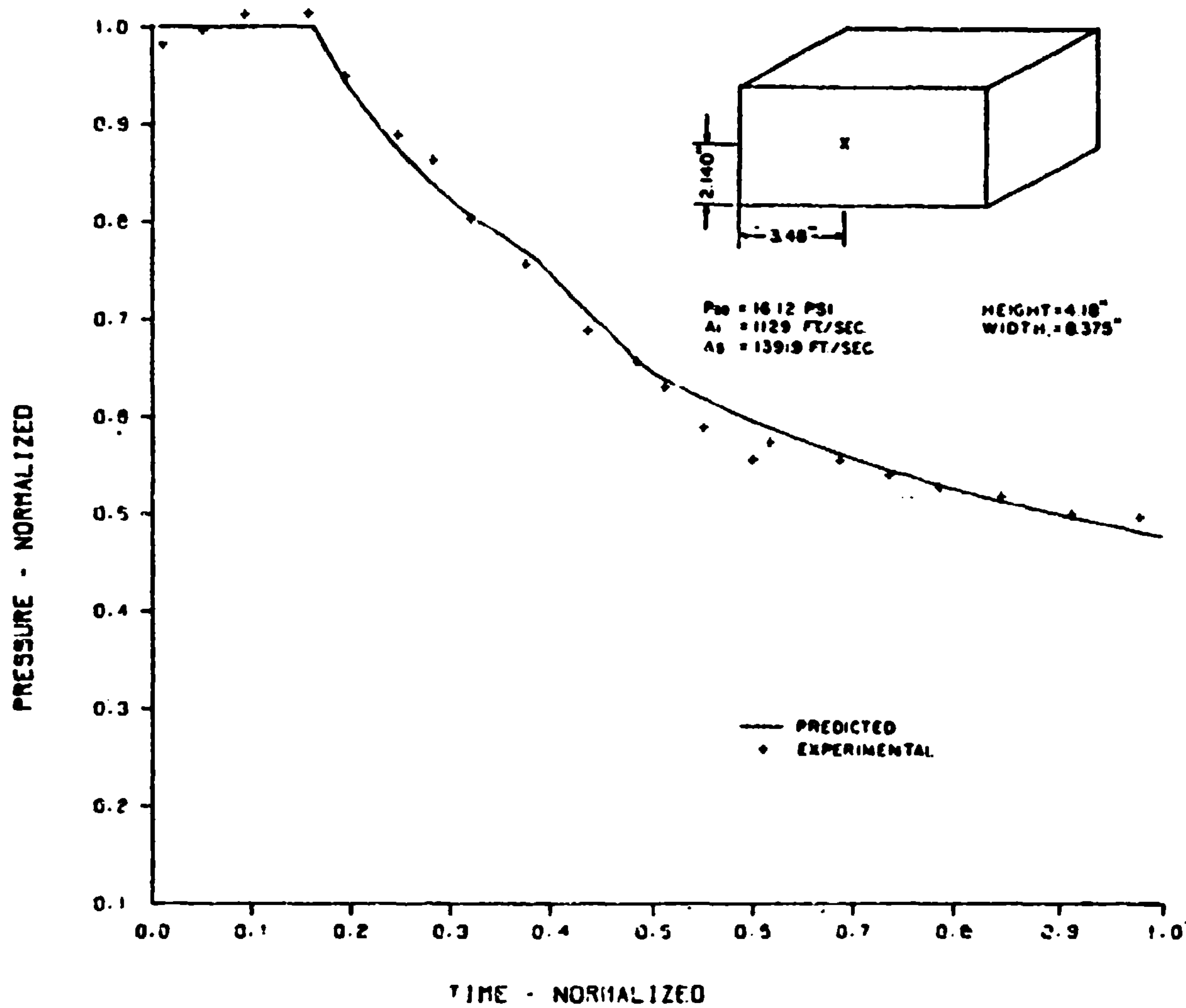
Least Square Fitting of Normalized P_2

Slide 4


SHOT NO. RS-12 POSITION NO. A
PRESSURE - NORMALIZED
TIME - NORMALIZED
2.140"
0.695"
Pso = 16.12 PSI
Ai = 1129 FT/SEC.
As = 1391.9 FT/SEC.
HEIGHT=4.18"
WIDTH=8.375"
PREDICTED
EXPERIMENTAL

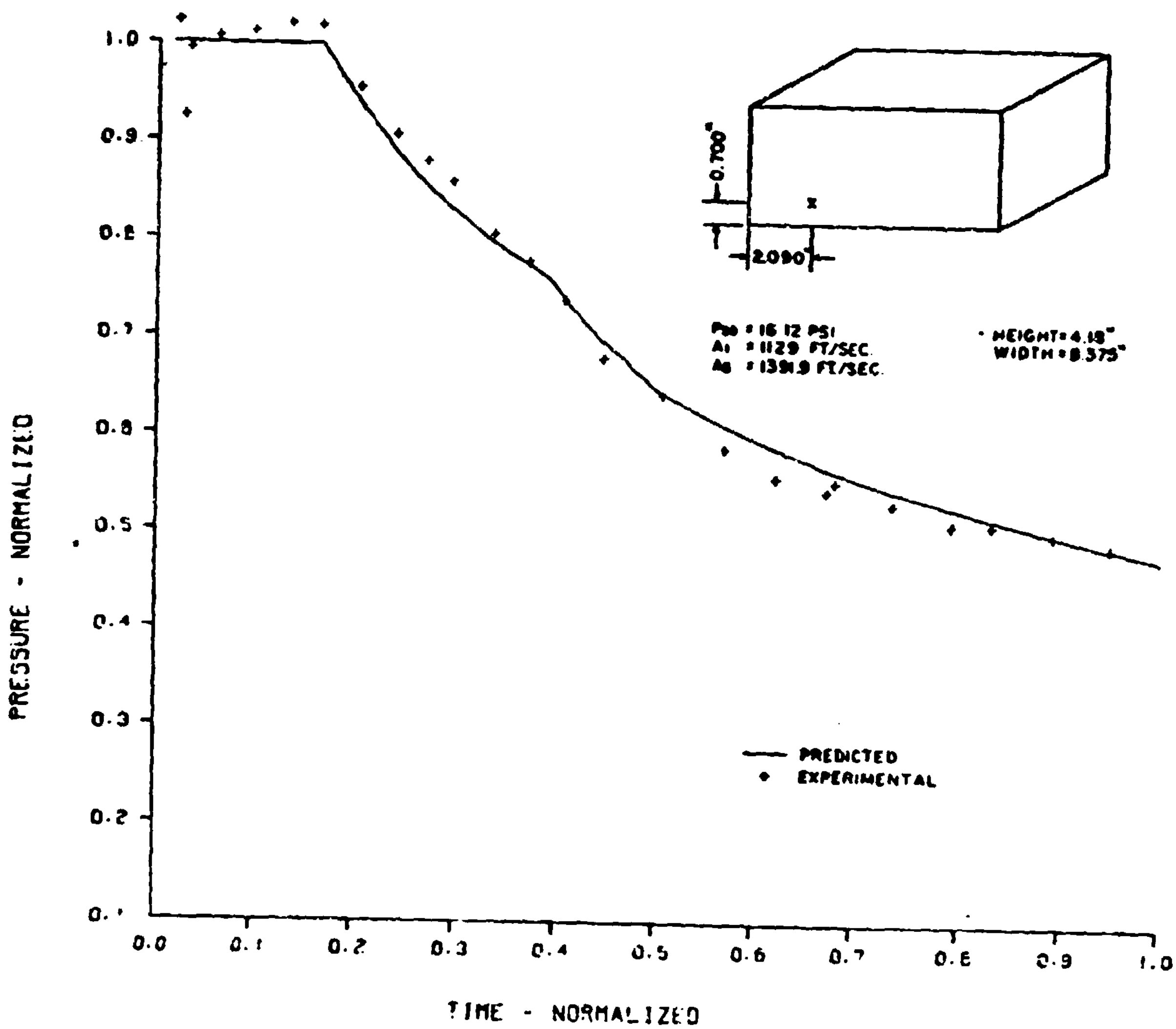
Slide 5

SHOT NO. RS-12 POSITION NO. C



Slida 6

SHOT NO. RS-12 POSITION NO. D



Slide 7

PREDICTION EQUATION FOR OVERPRESSURE P AT TIME = t

$P = P_1$ at $T_1 \geq t \geq 0$ (At time of arrival of shock wave).

$$P = P_n \left[\frac{t}{T_n}\right]^{M_n} \text{ at } T_n < t \leq T_{n+1} \leq T_5$$

where $n = 1, 2, 3$ and 4

P_1 = Reflected Pressure

P_5 = Stagnation Pressure

$P_{n+1} \equiv P$ at $t = T_{n+1}$

T_n = Time of arrival of "n" th rarefaction

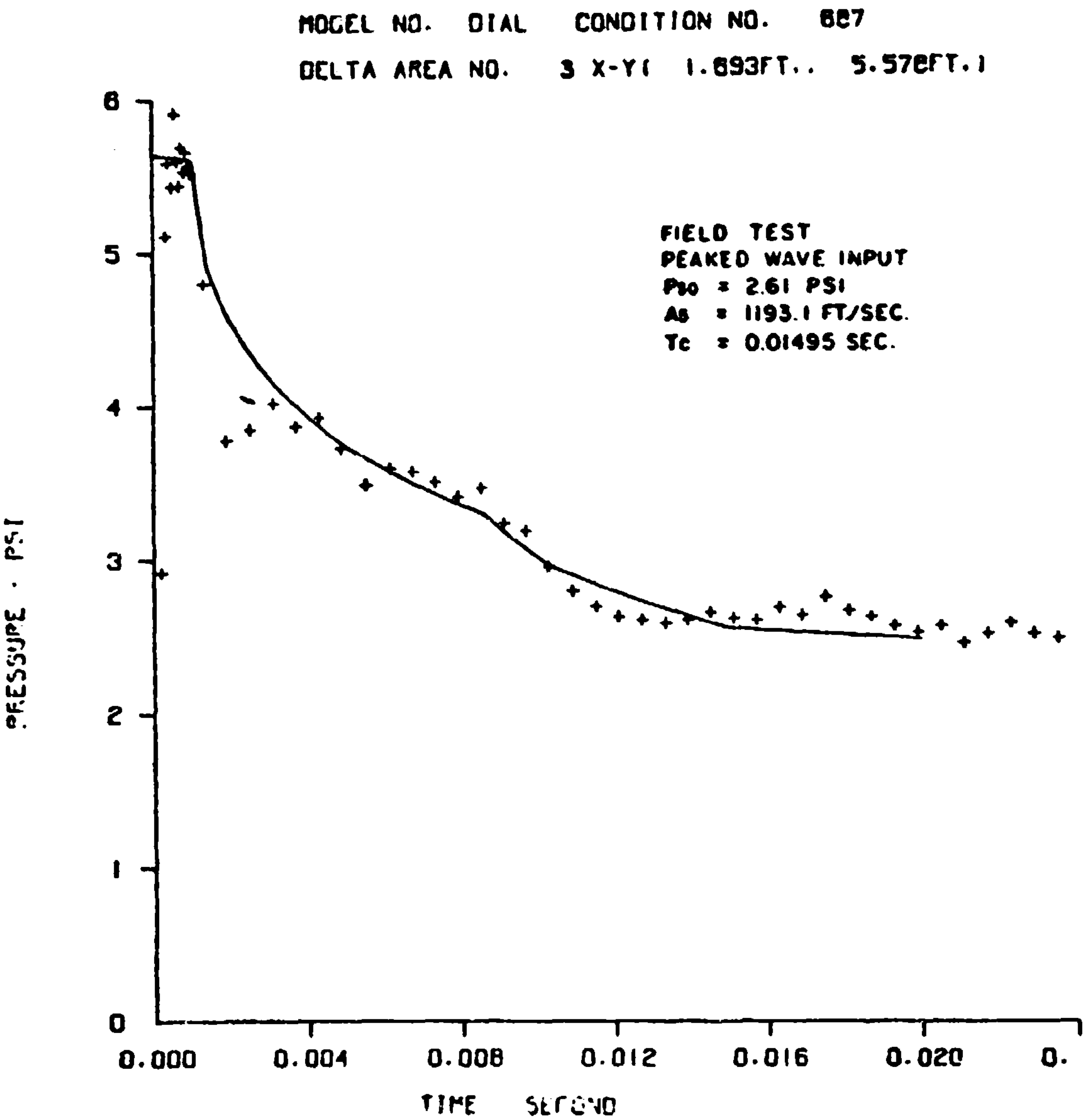
$T_5 = 3h' / A5 =$ Clearing time

h' = Clearing Height (The height or one-half the width, whichever is least)

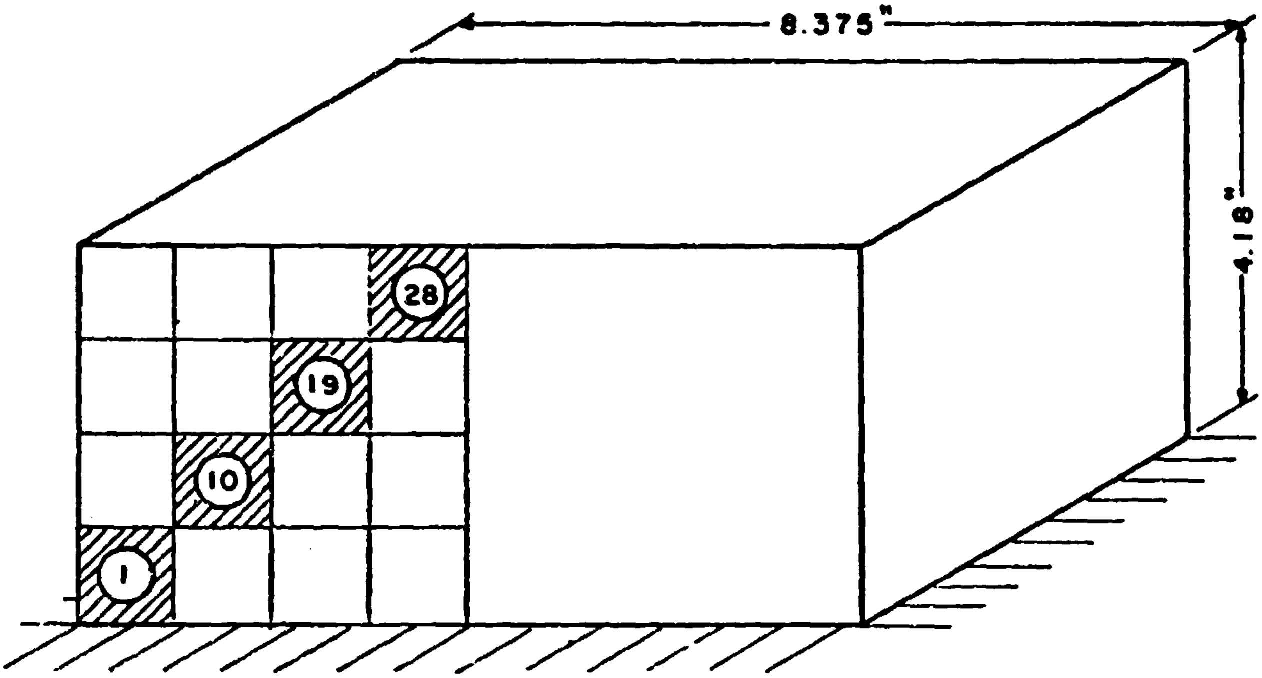
A_5 = Sound velocity in the region of reflected shock pressure

$$M_n = \frac{\log_{10}(P_{n+1} / P_n)}{\log_{10}(T_{n+1} / T_n)}$$

Slide 8


MODEL NO. DIAL CONDITION NO. 687
DELTA AREA NO. 3 X-Y(1.693FT.. 5.578FT.)
FIELD TEST
PEAKED WAVE INPUT
Pso = 2.61 PSI
As = 1193.1 FT/SEC.
Tc = 0.01495 SEC.
PRESSURE - PSI
TIME SECOND
0
1
2
3
4
5
6
0.000
0.004
0.008
0.012
0.016
0.020
0.

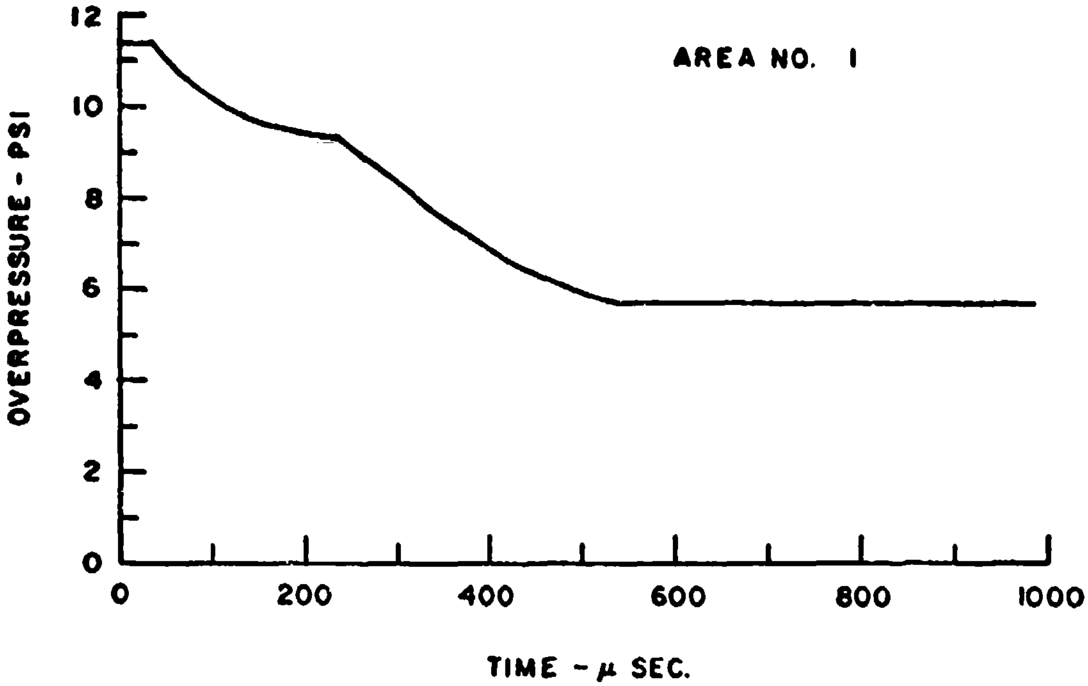
Slide 9

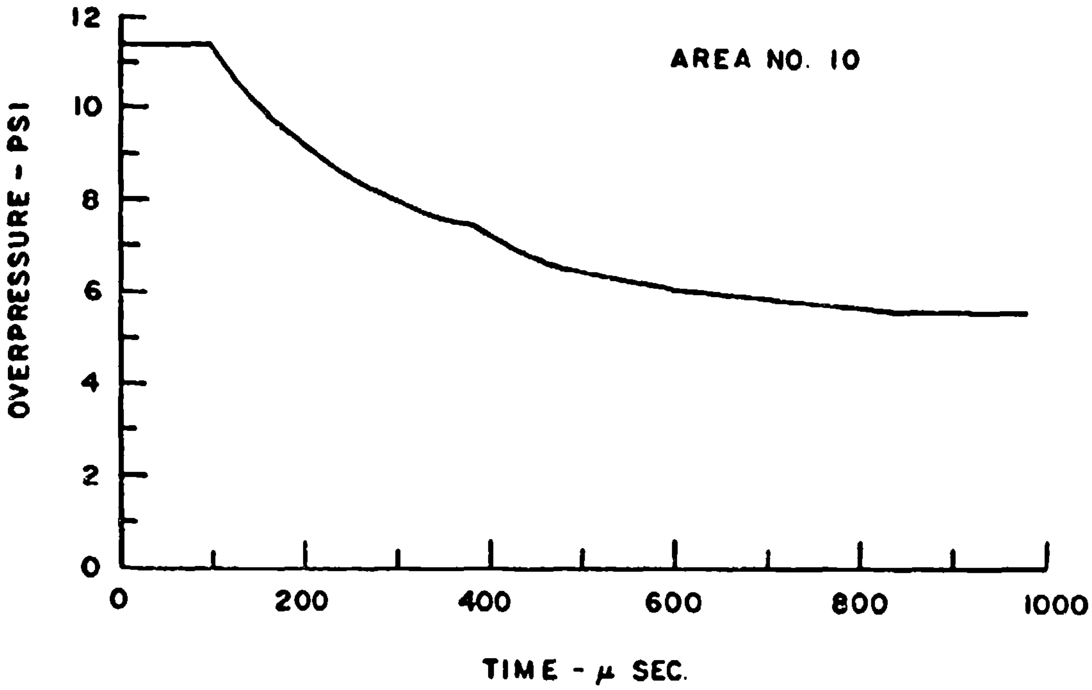


P_{SO} = 5.0 PSI
A_1 = 1128 FT/SEC.
A_5 = 1225.2 FT/SEC.

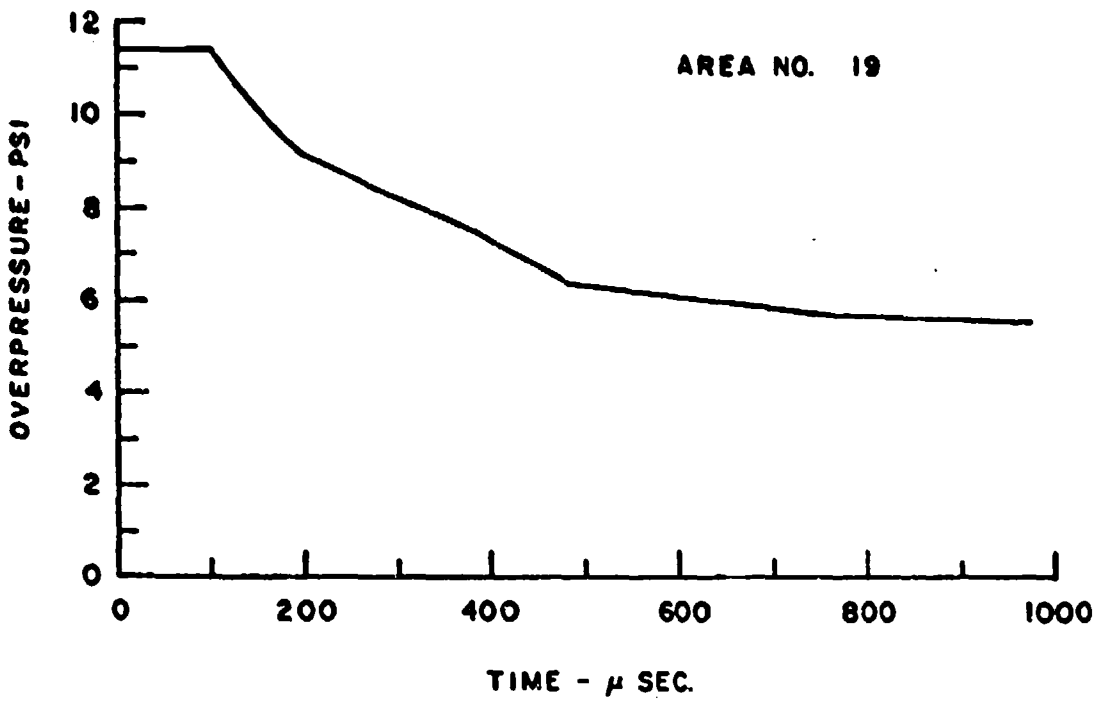
AREA INCREMENTS – MODEL RS-1

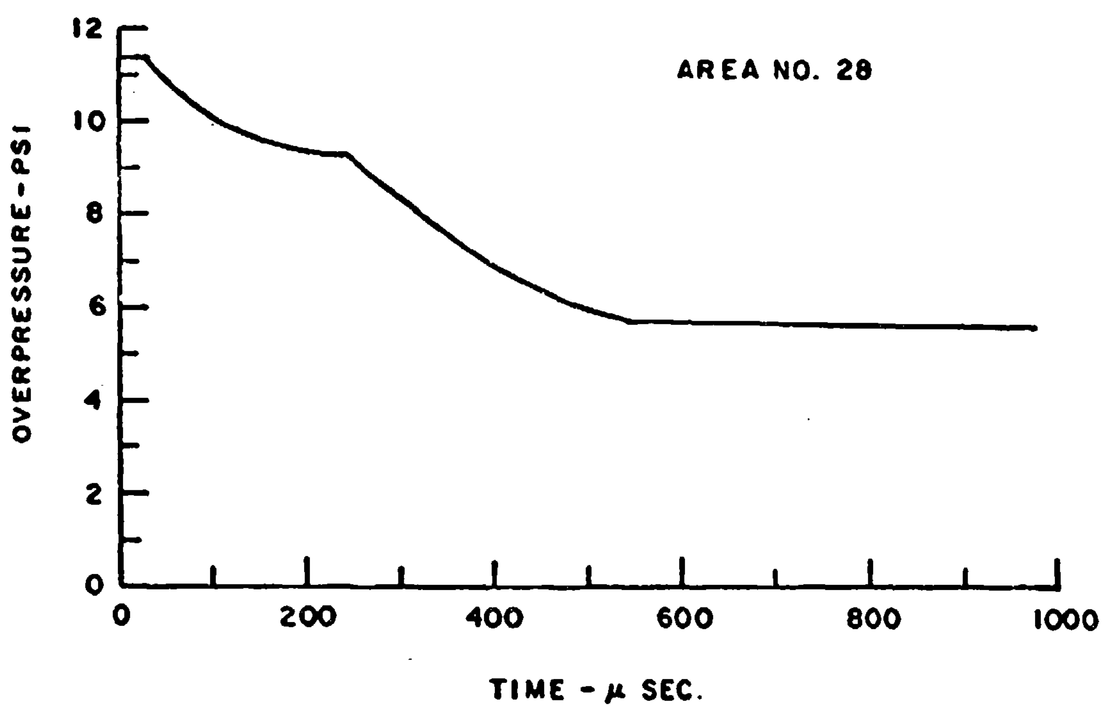
Slide 10





PREDICTED OVERPRESSURE - MODEL RS-1
Slide 11





PREDICTED OVERPRESSURE - MODEL RS-1
Slide 12

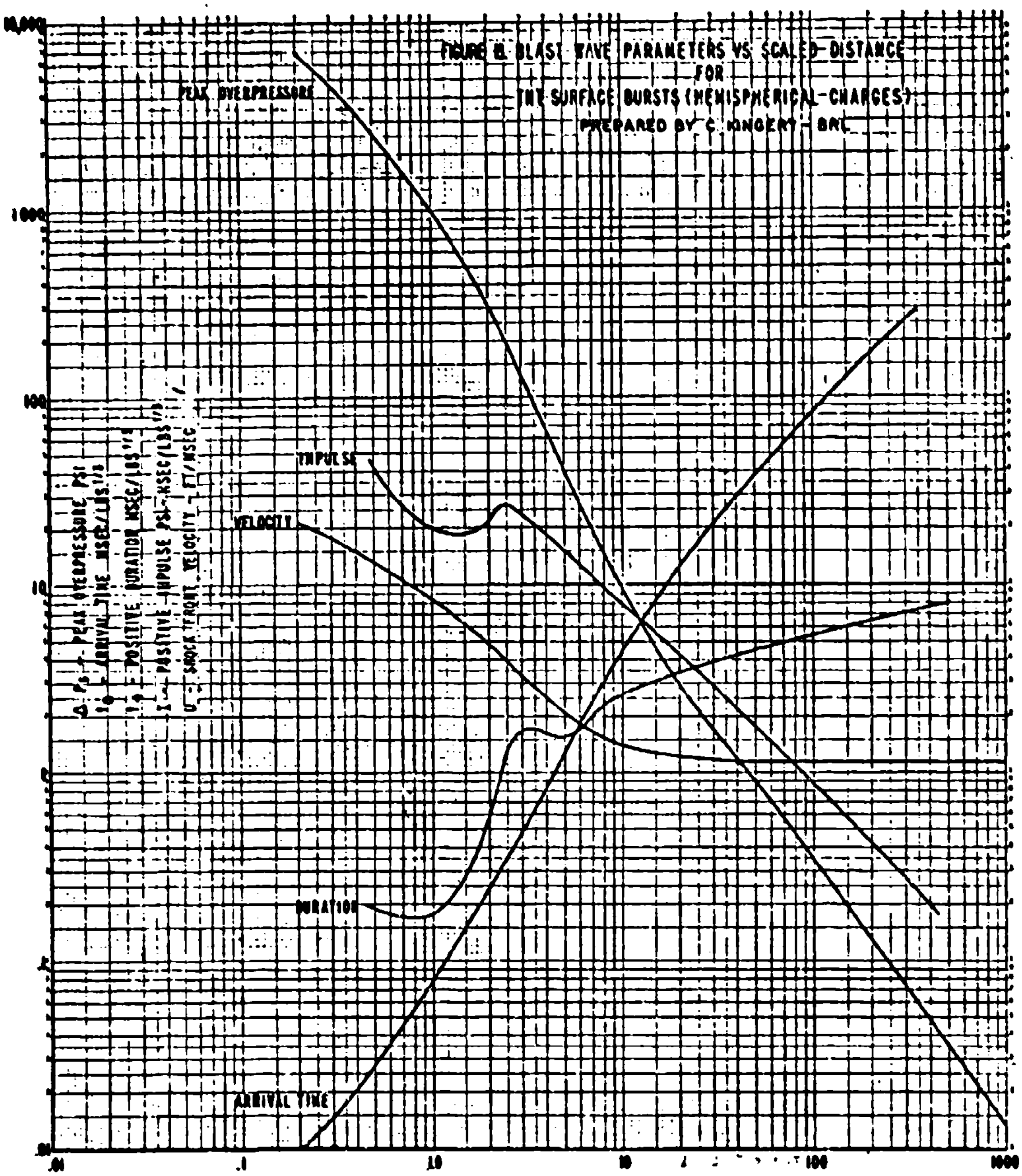
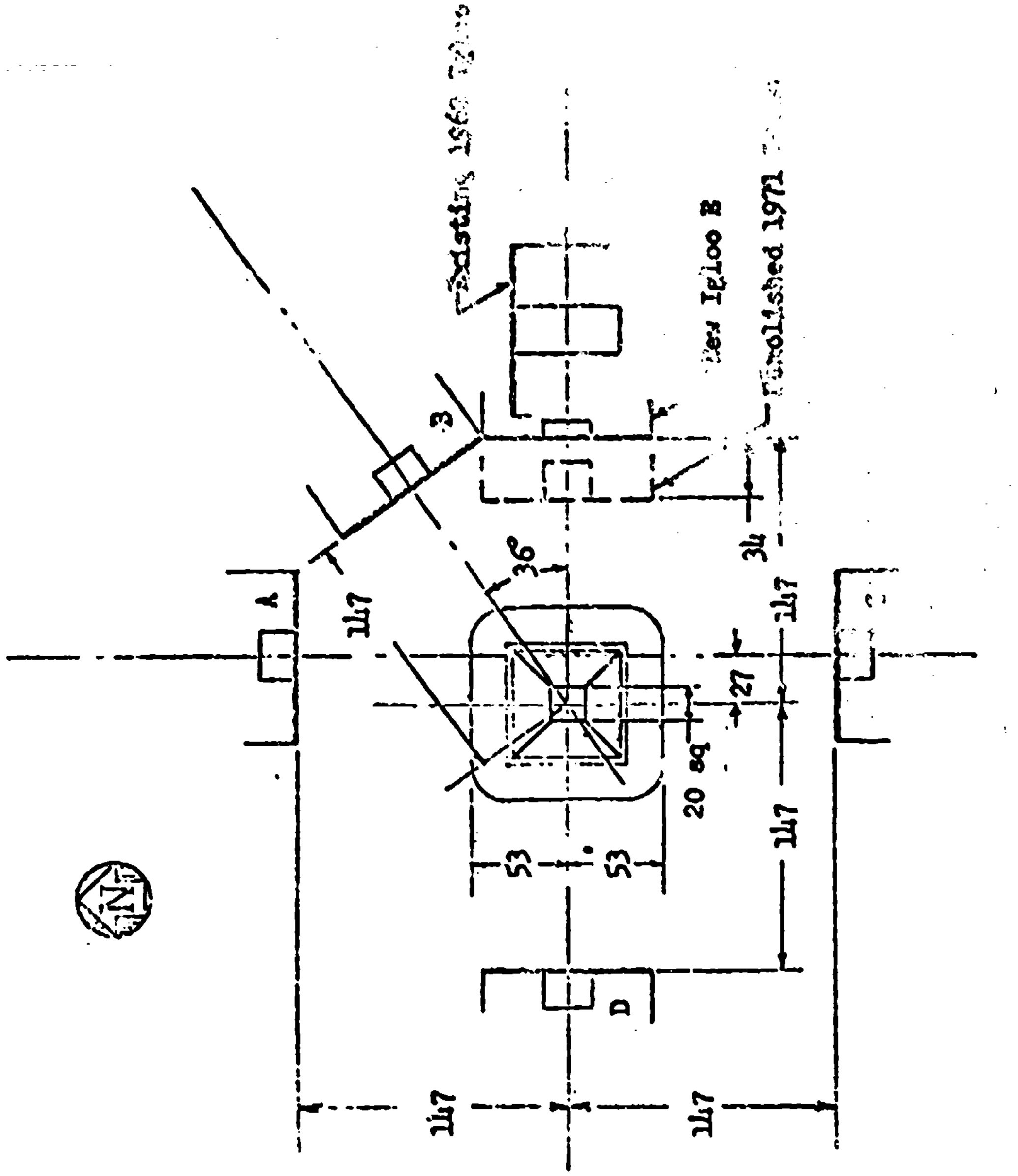


FIGURE 8 BLAST WAVE PARAMETERS VS SCALED DISTANCE
FOR
TNT SURFACE BURSTS (HEMISPHERICAL CHARGES)
PREPARED BY C. KINGERY - BRL
PEAK OVERPRESSURE
IMPULSE
VELOCITY
DURATION
ARRIVAL TIME
10,000
1000
100
10
.01
.1
1.0
10
100
1000
GROUND RANGE λ (FT/LBS 1/3)

Slide 13



ESKIMO II Test [illegible] Layout

Slide 14

BLAST DESIGN CRITERIA FOR IGLOO MAGAZINES

R. R. Watson
Ministry of Defence
United Kingdom

SUMMARY

Traditional ad hoc tests at full scale to assess particular separations for explosives storage buildings are too costly to permit useful replication and evaluation of the many other parameters involved in the performance of structures under dynamic loading by blast. NATO Group AC/258 has been formulating design and separation criteria for Igloo magazines. The United Kingdom has performed five tests on one-tenth scale models with extensive instrumentation and a lay-out designed to complement United States Eskimo Trials. The techniques are discussed and the results are compared with full scale tests at China Lake in 1963, 1971 and 1973. Recommendations are made for the design of future tests in respect of donor charge geometry, instrumentation, blast simulators, and the extension of performance criteria to other areas in the field of Quantity-Distances for explosives and ammunition.

INTRODUCTION

The NATO Group of Experts on Safety Aspects of Storage & Transport of Ammunition and Explosives (AC/258) provides a valuable forum for the free exchange of views and news on explosives safety criteria. In 1970 the Group started to formulate criteria for the NATO Manual relating to Igloo magazines. Naturally it took existing United States standards very much into account but did not feel constrained by these precedents. For one thing much of the US data derived from ad hoc tests at Quantity-Distances evolved for specific structures and operational requirements, whereas other countries proposed to develop alternative structures of the general Igloo type. Another reason was the desire, particularly by the structural engineers in the Group, to establish basic design and performance standards in terms of blast loading and tolerable behaviour, rather than specific structures and separations, in order to give greater freedom to engineers to design the optimum solution to each problem.

A co-ordinated programme of testing was evolved wherein the US undertook to keep the Group fully informed on the design and results of its full scale tests known as Eskimo Trials; the UK concentrated on the acquisition of blast data by fully instrumented model tests; and Norway pursued the design of Igloo doors and door-frames and their testing by blast simulators.

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One advantage of testing models is that the experimental design is more easily changed from shot to shot in the light of results. The first two tests in the UK preceded Eskimo I and gave useful support for the separations chosen for the first full scale trial. Thereafter the orientation of some of the acceptor magazines was changed at the request of the US in order to supplement the observations in Eskimo I. Again it was easy to change the instrumentation between model tests in the light of disappointments in the preceding model and full scale tests. Full scale tests may be more convincing for confirming conclusions from earlier work but model tests are more flexible for experimentation in the true sense where the results cannot always be predicted with confidence. However both types have their uses and this co-ordinated programme has given NATO the best of both worlds.

CONSTRUCTION OF MODEL IGLOOS

The US Army-Navy Explosives Safety Board had demonstrated by a series of tests at Arco, Idaho in 1946 that properly scaled models give a realistic indication of the way actual Igloo magazines behave under blast loading. In recent years the testing of models has become commonplace. In the United Kingdom the art and craft of building such models was developed mainly by staff of the Atomic Weapons Research Establishment at Foulness. The British Explosives Storage and Transport Committee therefore sought the facilities and guidance of AWRE Foulness in order to manufacture a dozen or so models in reinforced concrete, using a portal design suitable for mechanical handling equipment and palletised stocks of ammunition. The Department of the Environment worked out the design; AWRE trained the craftsmen of the Shoeburyness Proof & Experimental Establishment to make the models; and ESTC staff designed the tests which were conducted at the Shoeburyness Ranges in 1971 and 1972.

Figures 1 to 4 show the sort of techniques that are involved in making these models. It is important that the fine reinforcing wires are galvanized and are carefully tied and covered and that the concrete is not cracked prior to the tests. Ordinary bucket and shovel methods for mixing concrete are quite unacceptable. They proved relatively expensive to make. Each of the five trials averaged about $ 30,000 for constructing a donor and three or four acceptor Igloos and providing the necessary staff and overheads for instrumentation. This still compares very favourably of course with full scale trials such as Eskimo I which is understood to have cost about $ 400,000. This is why the UK could afford to run a series of five shots and so gather data on the reproducibility of replicate tests and the effect of changing certain parameters other than Quantity-Distance.

TEST RESULTS WITH MODEL IGLOOS

The chief interest lay in establishing a scaled distance of 1.25 $W^{\frac{1}{3}}$ for side-to-side separation of adjacent Igloos and 2.00 $W^{\frac{1}{3}}$ for rear of donor to front of acceptor, as was the case in Eskimo I. Figures 5 to 7 show the lay-out and the damage which was minimal. The separate wing walls were thrown and some door slabs were pulled out during rebound conditions but there was no cracking of the monolithic Igloo walls, roof or floor slab. In the early tests some acceptor charges were included in the acceptor Igloos (Figure 7) comprising anti-tank mines and bangalore torpedoes (tubular demolition charges). They were not even much disturbed so were omitted from later tests.

In order to show that bulk explosives could be treated the same as cased explosives in Igloos, Test 2 utilised a donor with a steel case giving 20% charge weight ratio. Otherwise the donor charge was identical to that in the other tests, namely 64 kg CE/TNT (tetryl/TNT) demolition slabs initiated by plastic explosive and electric detonator. The donor dimensions were chosen to simulate stacking of ammunition in a real Igloo. One minor criticism of all the Igloo tests at China Lake since 1963 is that every shot seems to use a different donor type, thus confounding any attempt to determine the effect of changing other parameters.

Figure 9 shows clearly that the donor explosion breaks through the rear of the Igloo almost as soon as through the front. This was not really expected. It emphasises the difficulty of properly analysing a donor explosion since the variables may include donor type, donor shape and donor Igloo asymmetry.

Having established that $1\frac{1}{4}$ $W^{\frac{1}{3}}$ and 2 $W^{\frac{1}{3}}$ were adequate, Tests 3 through 5 changed the orientation of the West acceptor at the request of DoDESB in order to correspond more exactly to the situation in Eskimo I. Another change was the introduction of ballast to increase the inertia of the nearest acceptor by the scale factor. It was thought that the distribution of energy in the target structures might be different on the model and full scales owing to differences in rate of movement. Figure 12 shows the external ballast - two concrete blocks. Scrap iron was also used, inside the Igloo. The structure remained undamaged. However the change in orientation of the West Igloo, to be facing the donor, resulted in much greater deformation of the doors (Figure 13).

In Firing 4 a striped backboard was used to reveal the shock-front as it passed over the door barricade of an acceptor Igloo at the Intraline Distance (NATO value of 20 $W^{\frac{1}{3}}$). Eskimo I had shown the hazard of an Igloo with its door facing the donor's door at 2 $W^{\frac{1}{3}}$. Test 4 examined the possibility of bracketing the distance which might be tolerable. Figures 14 & 15 show the set-up and the unperturbed shock profile. Ten years ago there might have been surprise that an earth barricade affects the shock so little but nowadays it is well established.

Test 5 was basically a calibration shot using the same lay-out as before but a bare charge as donor - bare in the sense of there being no donor Igloo around it. It was carefully located on the same type of foundation slab as before (Figure 16). The aim was to measure the increase in crater and the reduction in blast loading on acceptors attributable to the presence of the donor structure in Tests 1 through 4. Test 5 was dramatically different from the others. The East acceptor, side on to the donor, merely had its doors more badly deformed but the West Igloo (Figure 18) which faced the donor at 2 $W^{\frac{1}{3}}$ suffered complete failure of the headwall, parts of which impacted on the rear inside wall so hard that scabbing was caused on the outer rear face. Any ammunition within must surely have been at risk of initiation. The North acceptor (Fig 19) was also cracked and its doors severely buckled. The instrumentation recorded this increase in blast due to the absence of a donor structure to smother the blast to any extent.

INSTRUMENTATION

Great importance was attached to providing generous instrumentation to measure blast loading on the acceptor Igloos (headwall, roof, side-wall) and the far field shock intensity (Intraline and Inhabited Building Distances). There were many problems in trying to measure the transient loading under the earth cover of the roof and side-walls. The relatively small signals were masked by high noise which was later identified as coming from the line for the initiation circuit, presumably due to ionisation effects after the firing leads had gone open circuit at zero time. This was cured for Test 5 by keeping firing leads in a totaly different plane from gauge leads, using an overhead gantry to take the firing line up vertically from the donor and so avoid induced signals in the gauge lines. Figure 20 shows how some of the earth cover was removed to get intermediate measures of the cushion effect of this cover on an acceptor Igloo.

On the whole the measurements of blast loading on headwalls were very successful. The data greatly supplements that from Eskimo I and has been used by the NATO Group to formulate design criteria of 3 bar or 7 bar, depending whether the acceptor is side-to-side at $1\frac{1}{4}$ $W^{\frac{1}{3}}$ or face-on to a donor at 2 $W^{\frac{1}{3}}$. The corresponding criteria for scaled time of the blast loading and scaled positive impulse per unit area are 1 millisecond per $kg^{\frac{1}{3}}$ and 2 bar ms $kg^{-\frac{1}{3}}$, in both cases.

COMPARISON WITH FULL SCALE TESTS

The Arco Tests in 1946 used merely paper diaphragm blast meters so there was until recently no really convincing data to compare model and full scale situations. The results of the five model tests by the UK accord pretty well with the limited amount of data from the Eskimo shots. This can best be illustrated by looking at pictures of the most severely damaged headwalls.

The blast loading on the headwall of Acceptor A3 (Figure 19) was 41 bar recorded by a piezoelectric gauge beside the door and 54 bar above the door. This suggests about 600 to 700 psi peak overpressure (face-on) for cracking of the UK structure. Complete failure corresponded to 160 to 170 bar (about 2,400 psi) - Figure 18. It should be noted that this new portal design is particularly well reinforced to maintain monolithic behaviour. The North headwall in Eskimo I (Figure 21) suffered a load of something in excess of 16 bar (240 psi) judged from the nearest gauge reading, flush with the ground a few feet in front of the Igloo (taking the reflected peak value). This structure is not specially designed and would not be expected to be as strong as the UK portal Igloo.

Figures 22 - 24 show the damaged headwalls in Eskimo II trial and it is understood that the blast load was 200 to 300 psi (14 to 20 bar) peak.

As regards positive duration of the loading, the models had of course a much shorter load - 2 to 4 ms compared with a predicted 45 ms for the Eskimo II firing. The positive impulse per unit area in the model test (Figure 18) was 42 to 45 bar milliseconds (say 650 psi ms) on the headwall which failed so dramatically. It is understood the design value of positive impulse for Eskimo II was 1,100 psi ms and the measured values were up to 2200 (150 bar ms).

It is clear that when all the data from the model tests and from Eskimo firings 1, 2 and possibly 3 have been collated, there will be a really useful pool of quantitative information for structural engineers from which to assess the likely blast loading for various configurations of Igloos.

CONCLUSIONS

The NATO Group concluded from the results of the models and Eskimo I that separations of $1\frac{1}{4}\ W^{\frac{1}{3}}$ (side-to-side) and $2\ W^{\frac{1}{3}}$ (front-to-rear) are suitable for earth-covered magazines provided that they are constructed in reinforced concrete or with corrugated steel arches; that their roofs, side-walls and rear-walls are designed for the dead load pressures from the earth cover; and provided that their headwalls and doors are designed for the recently determined blast loads.

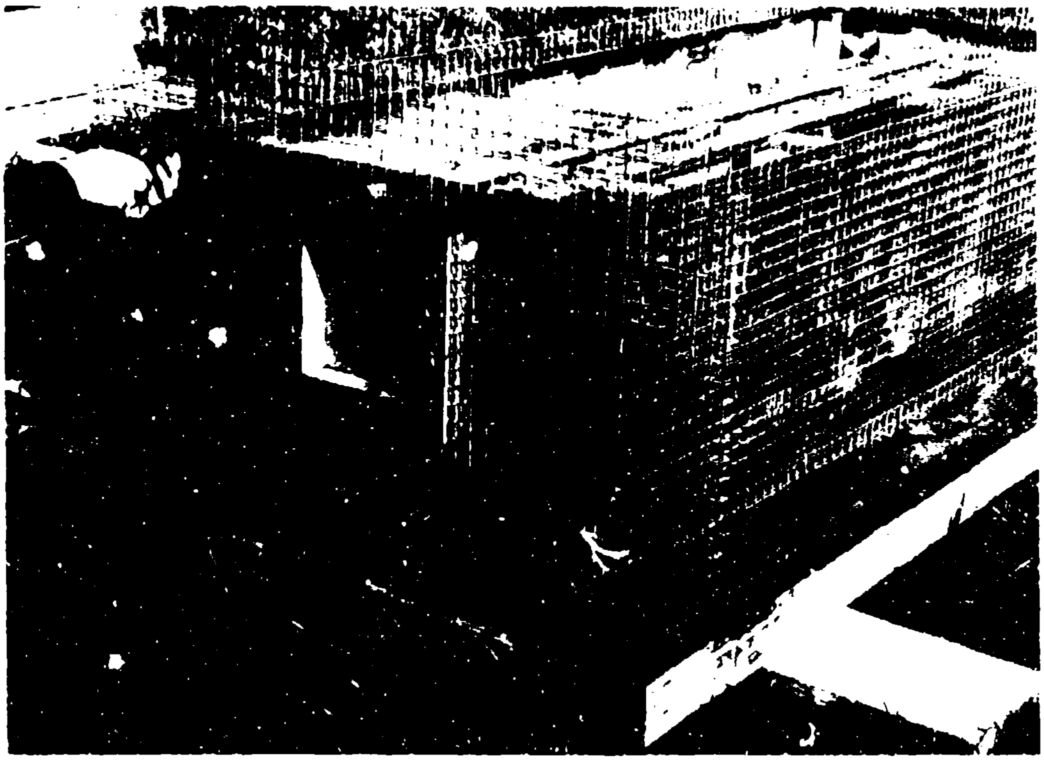
More work needs to be done to quantify the blast loading in the vicinity of open stacks and ordinary above-ground buildings in order to specify the load for Igloos in the vicinity of other types of storage buildings.

Various structural designs and modifications for headwalls and doors will have to be proven. Headwalls can be tested at model scale but there are great difficulties in modelling doors and door frames. Therefore full scale tests or the use of blast simulators will still have a role. Greater attention may be necessary to defining the tolerable performance quantitatively.

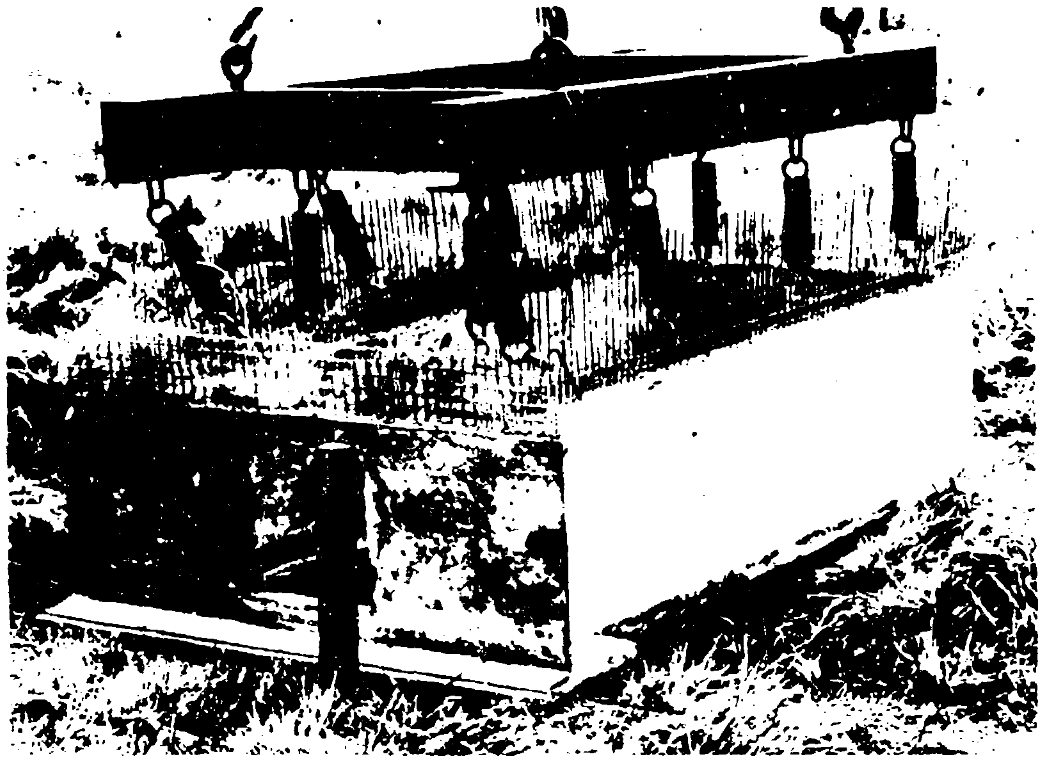
RECOMMENDATIONS

It is recommended that this type of technical co-operation should continue since not only does it avoid duplication of effort and expense but also it taps a greater source of ideas and solutions. Future tests should pay attention to the number of variables, in order to hold constant as many as possible, thus facilitating subsequent analysis and comparison of different trials. In particular the type and geometry of donor charges should be more standardised. The use of blast simulators should be explored to render less expensive the necessary tests on doors/door frames. Finally, the concept of defining blast environment and tolerable performance for structures should be extended to supplement the traditional, rigid Inhabited Building Quantity-Distances.

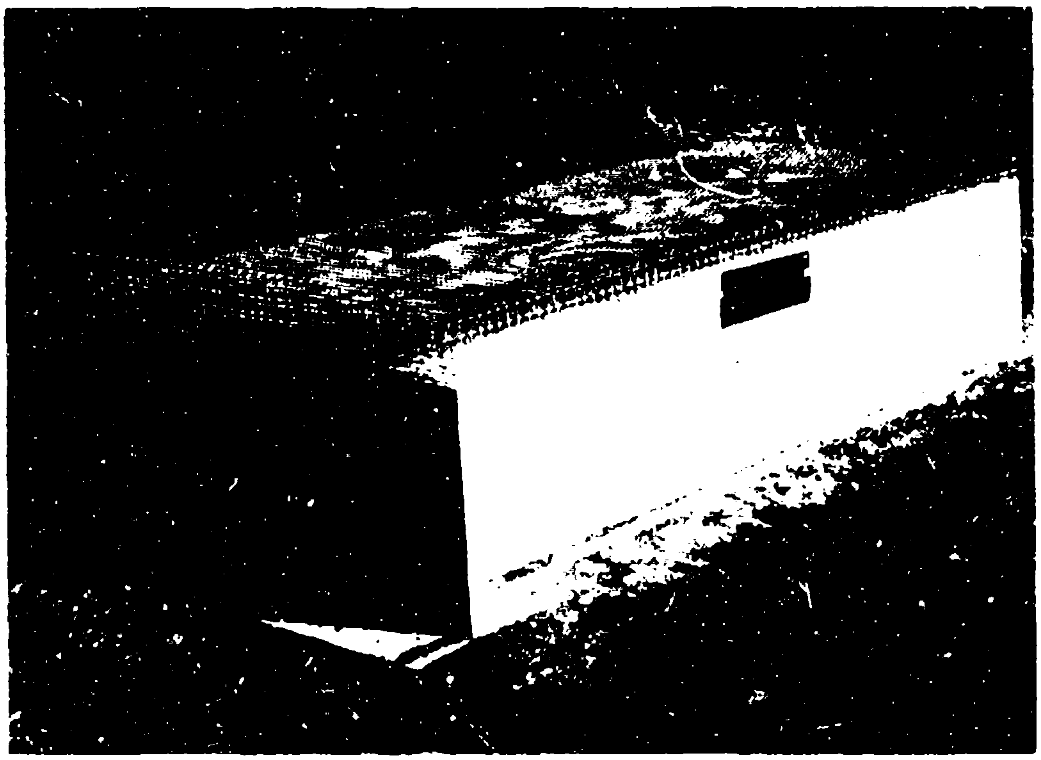
1. Preparing the base in workshop.



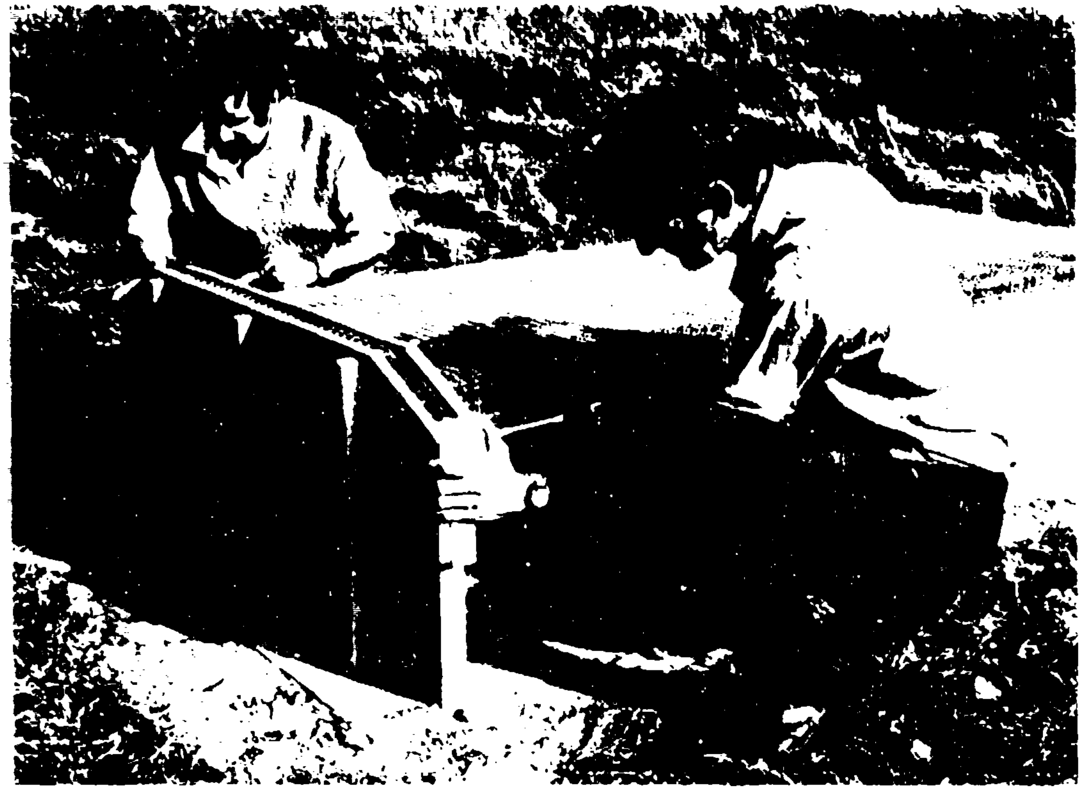
1. Reinforcement detail.



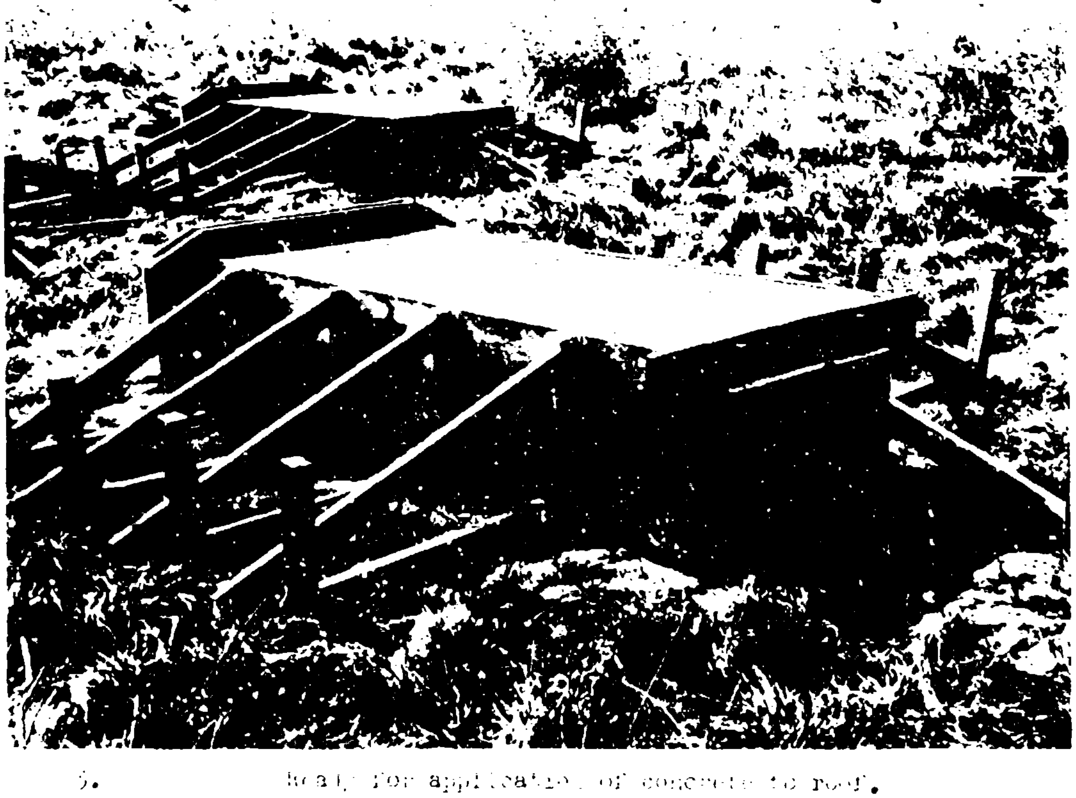
Careful placing of igloo to avoid cracking.



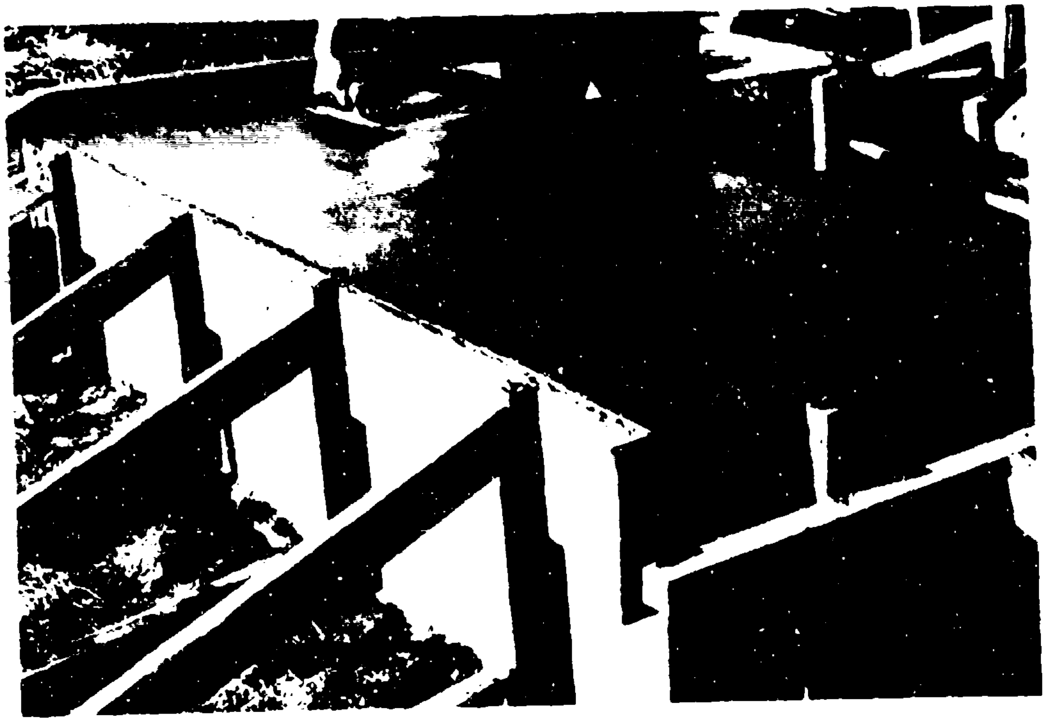
Installation completed.



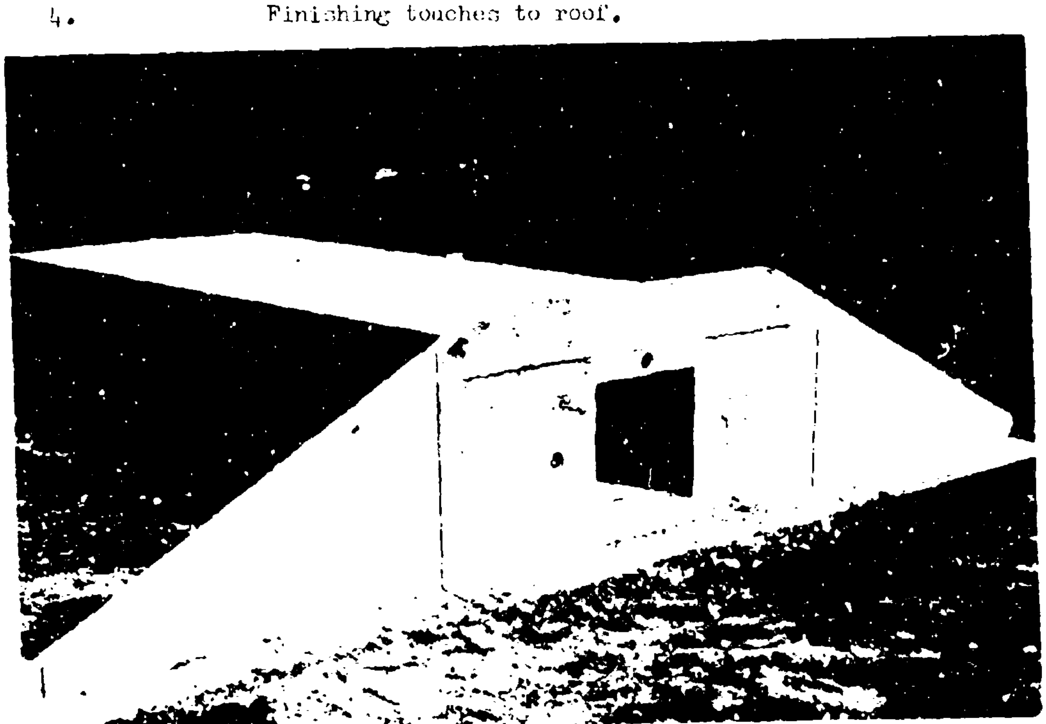
4. Shuttering for top of headwall.



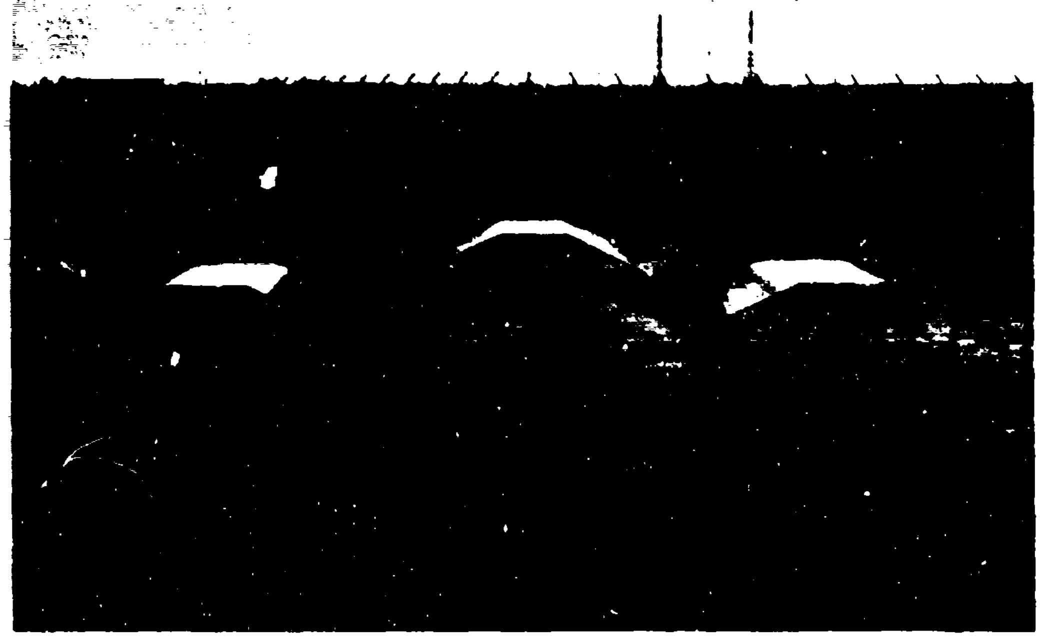
5. Ready for application of concrete to roof.



4. Finishing touches to roof.

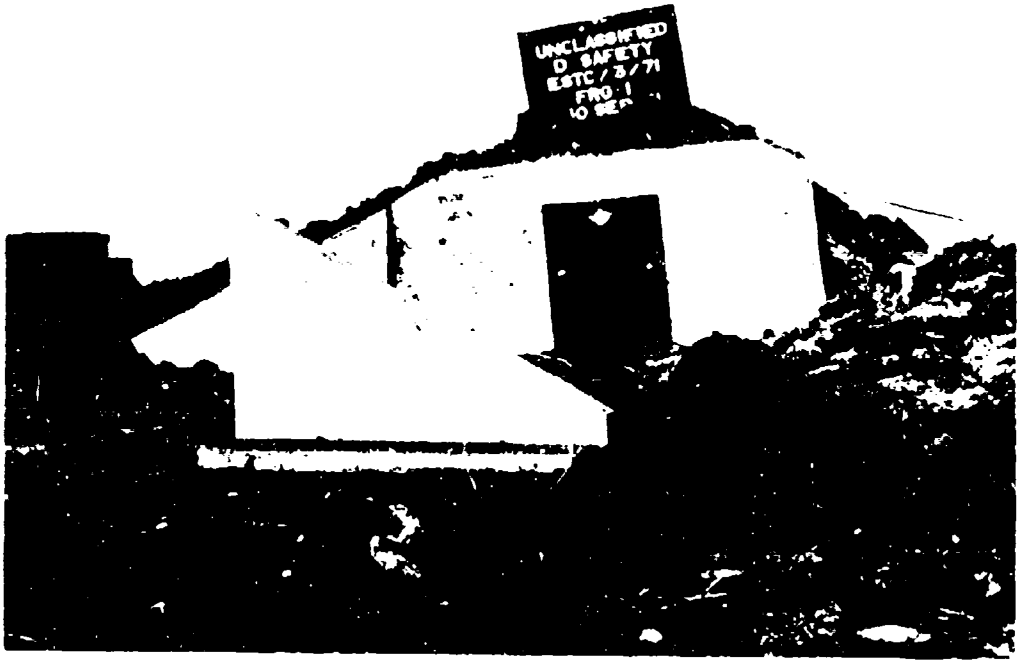


4. Completed igloo with separate wingwalls.

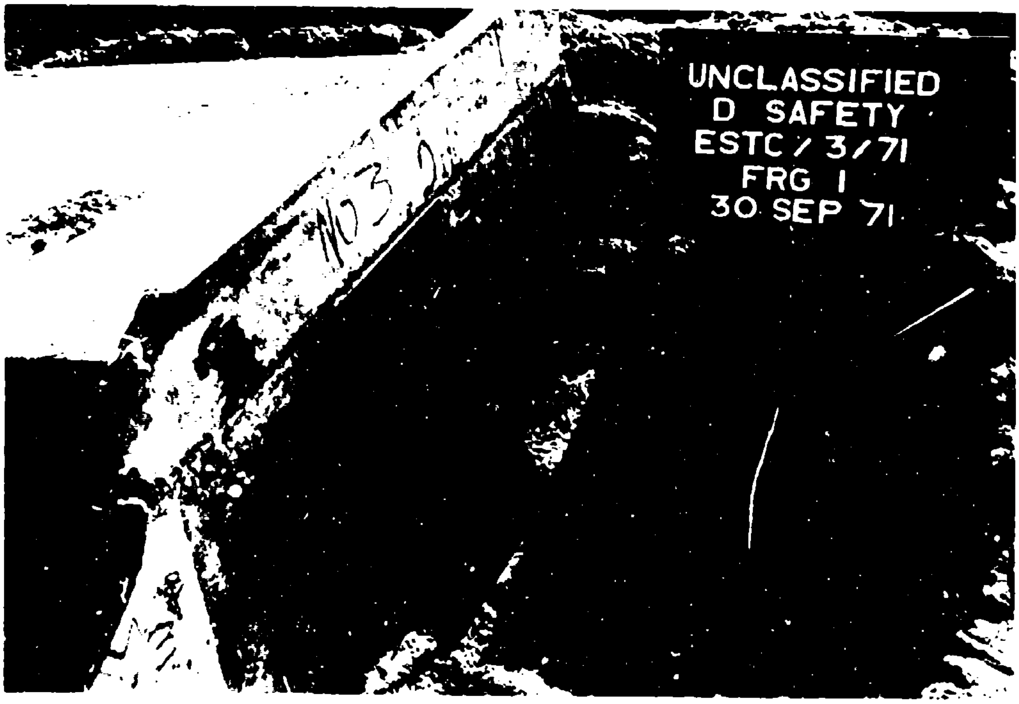


5. Layout before firing.

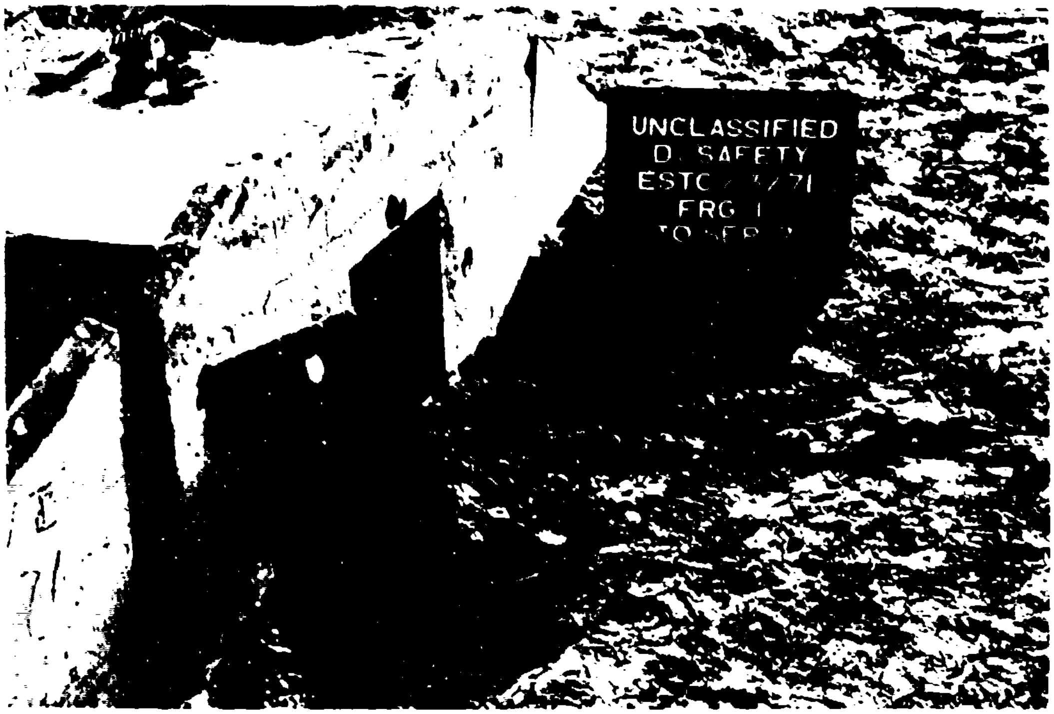
5. Layout after firing.



[illegible]. Acceptor A[illegible] after firing.



[illegible]. Damage to A[illegible] after firing.



7. Damage to A3 after firing.

7. Contents of A3 after firing.

6. Cased charge inside donor igloo.

[illegible] Fragments of donor casing.

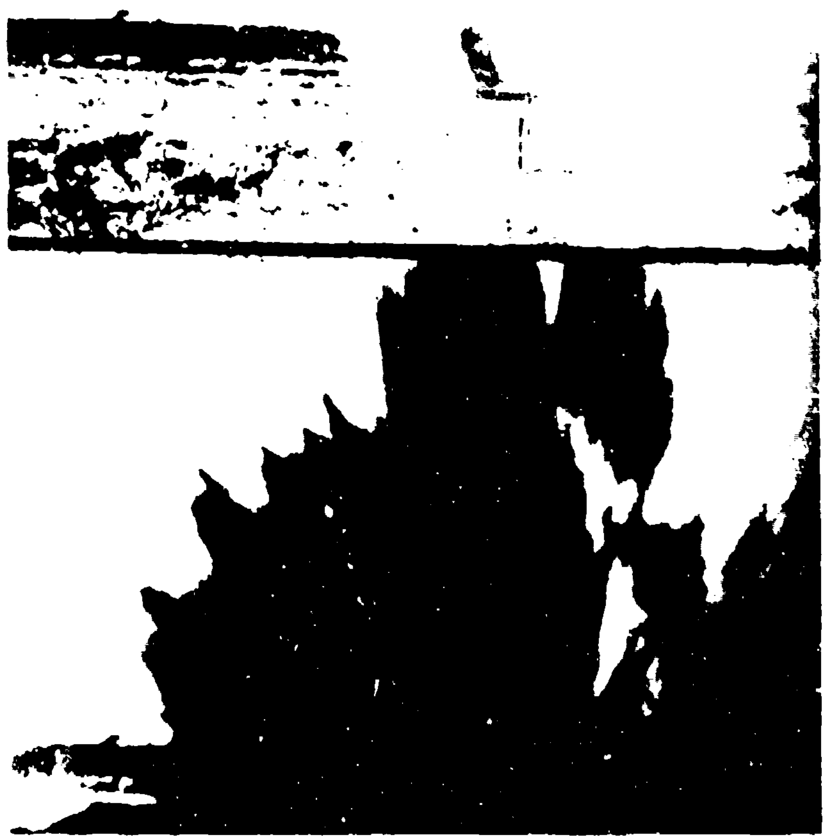
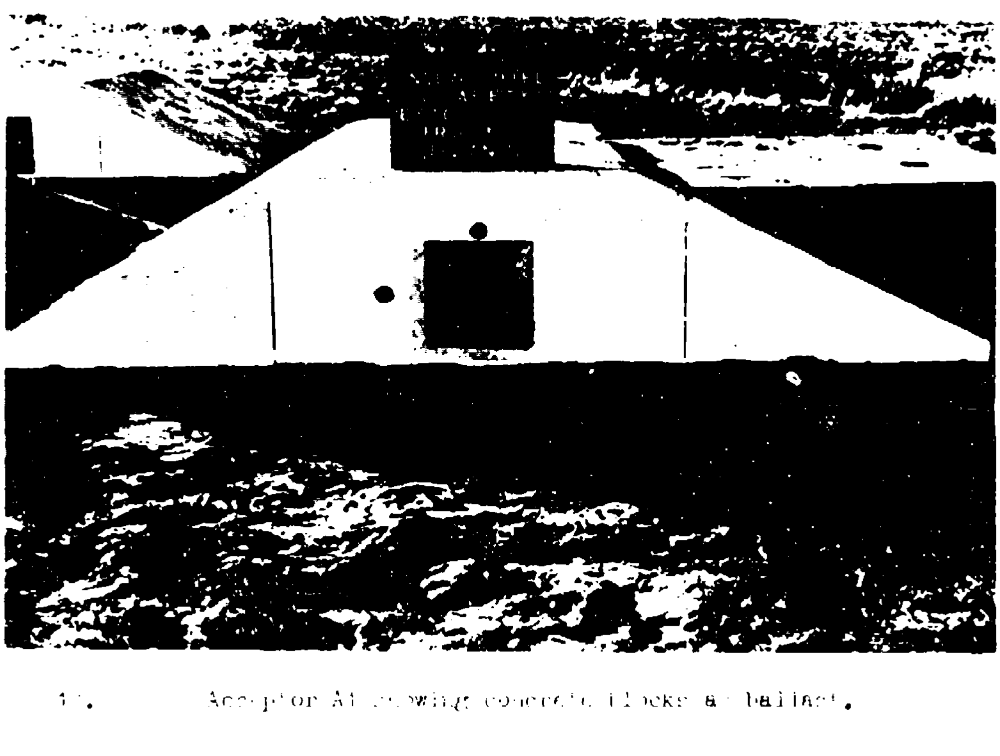
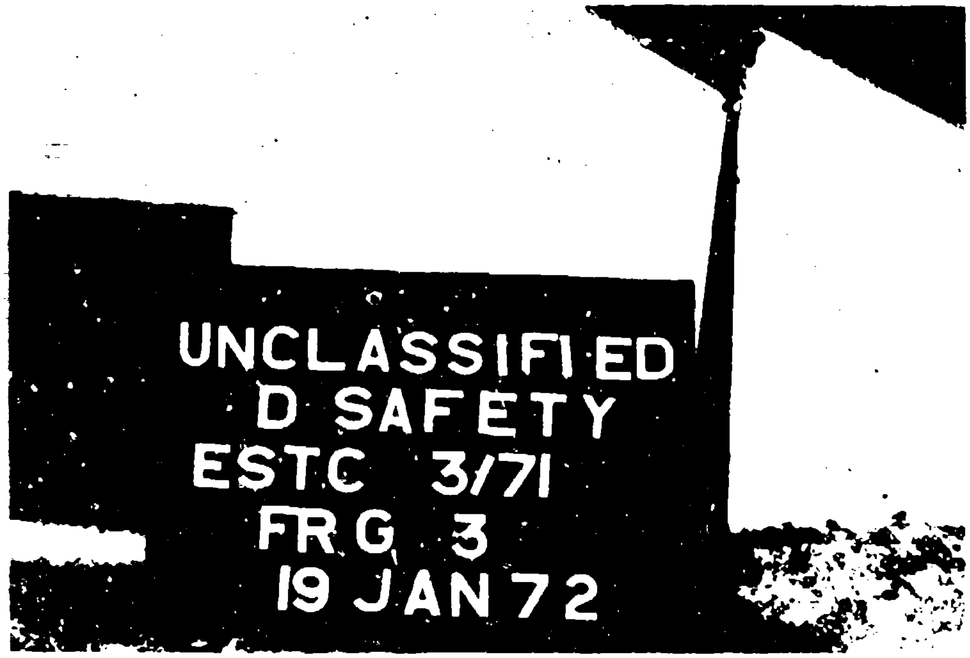


FIGURE 9

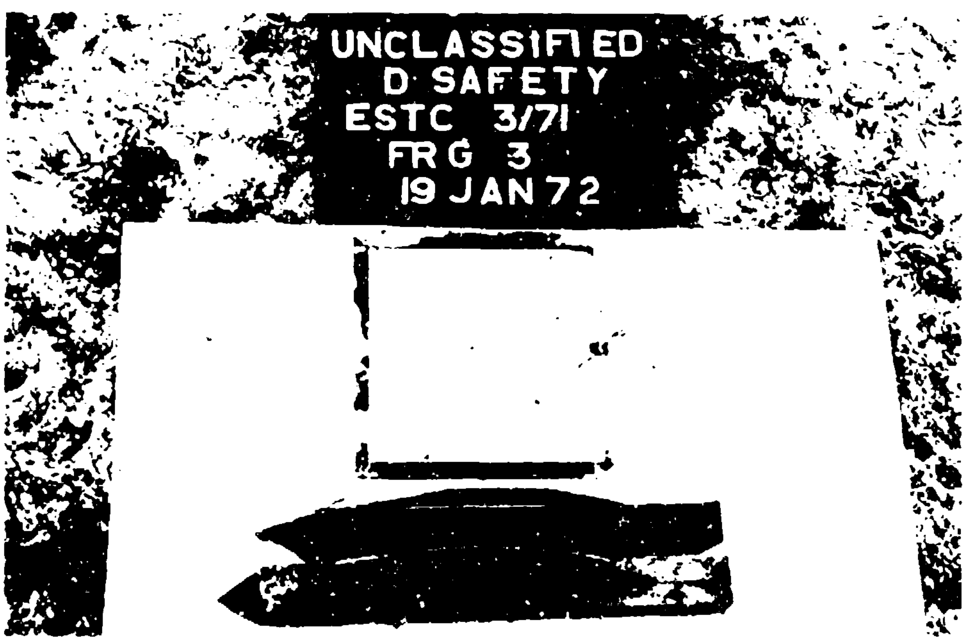
1[illegible]. Site before firing



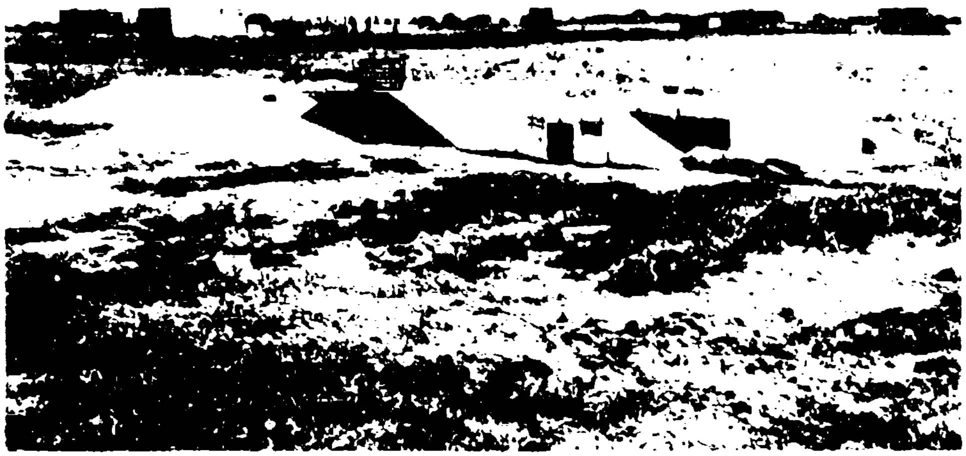
1[illegible]. Acceptor A1 showing concrete blocks as ballast.



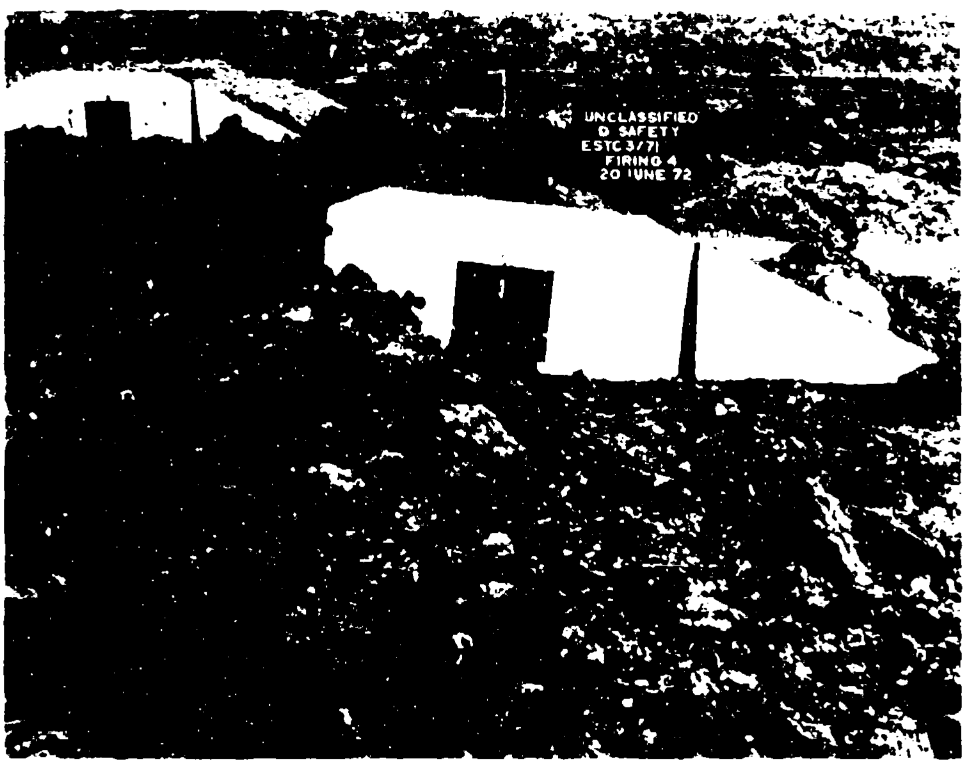
11. Crack in headwall corner of acceptor A1.



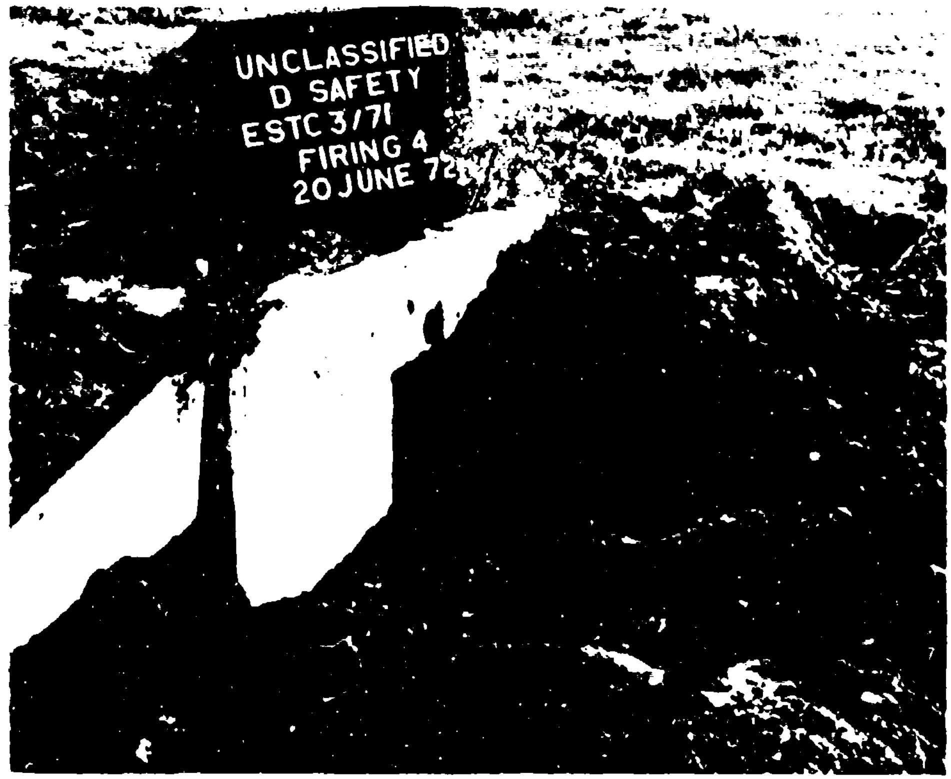
11. Door frame and doors of acceptor A1 showing warp.



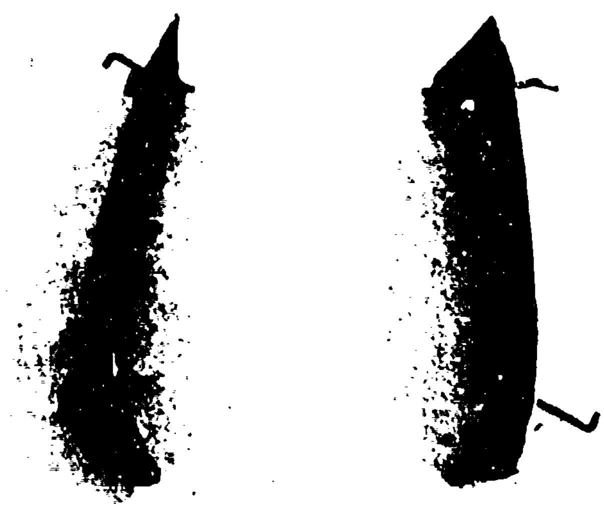
12. Layout before firing.



13. Acceptor A1 after firing.



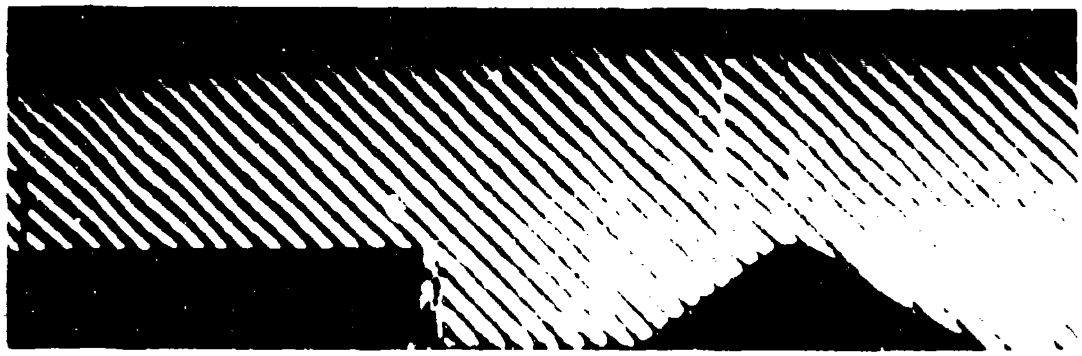
13. Acceptor A2 after firing, with spoil cleared from doors.



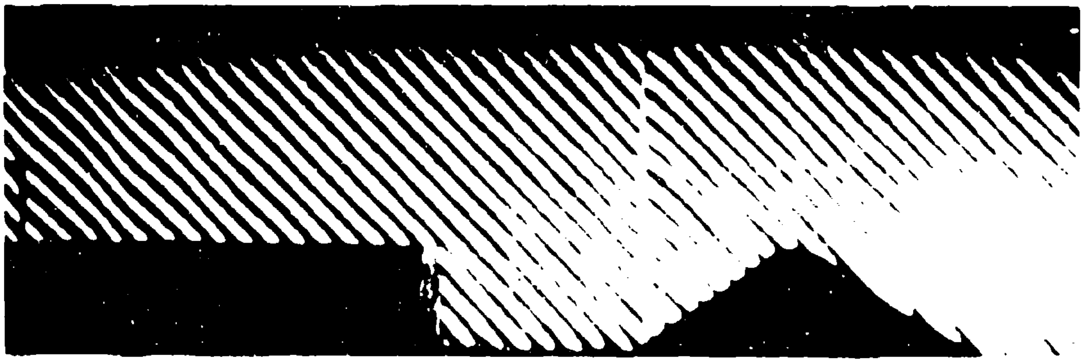
13. Deformation of doors of acceptor A2.

14. Acceptor A 3 after firing.

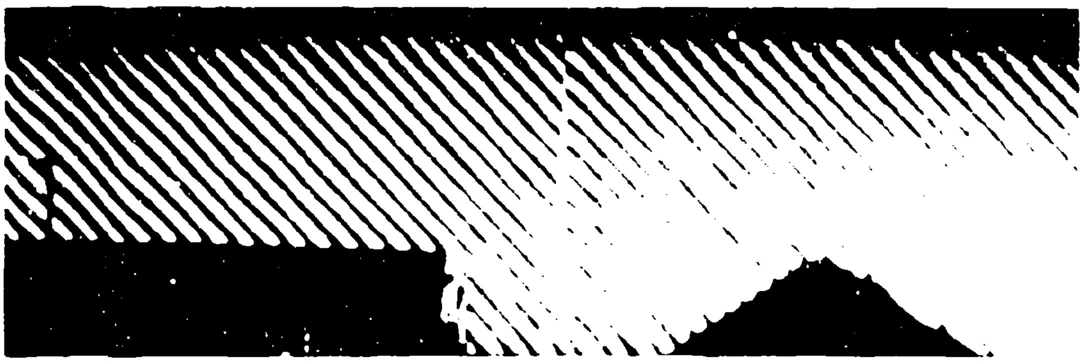
14. A cceptor A4 with door barricade and striped backboard.



Incident Blast Wave Profile (Time from T.o. 3 m/sc)



Incident Blast Wave Profile (Time from T.o. 4 m/sc)



Incident Blast Wave Profile (Time from T.o. 5 m/sc)

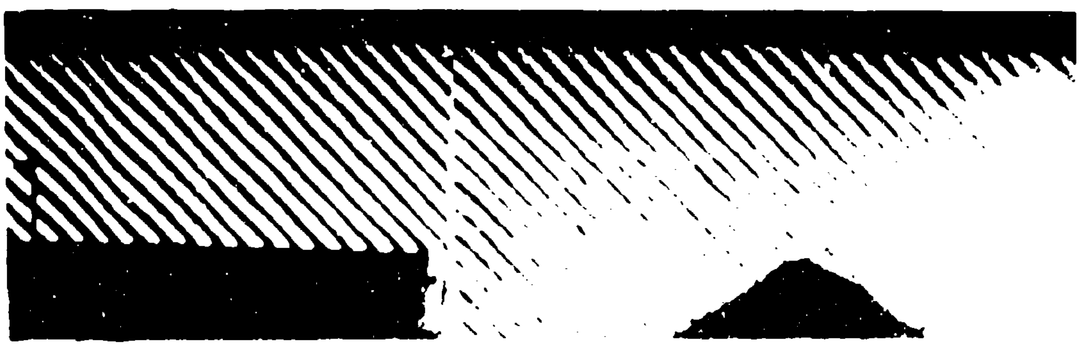
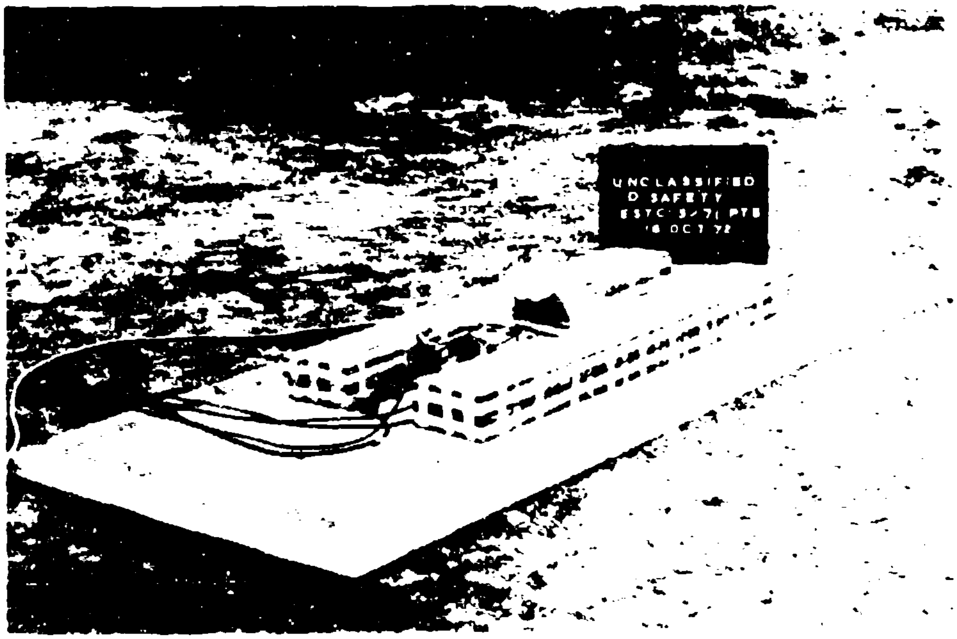
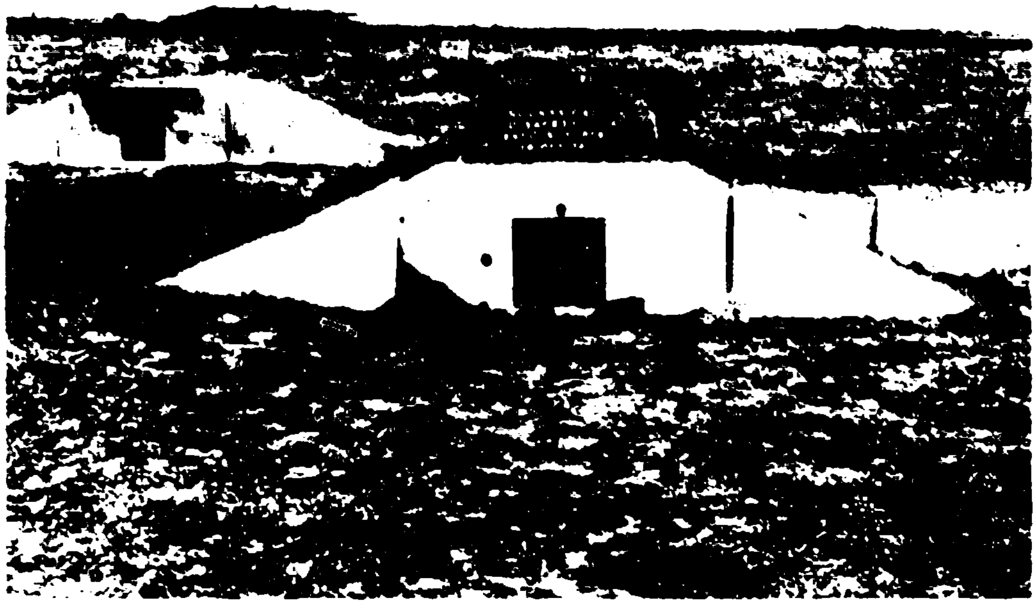


Figure 15

16. Layout before firing, acceptor A1 with ballast on right.

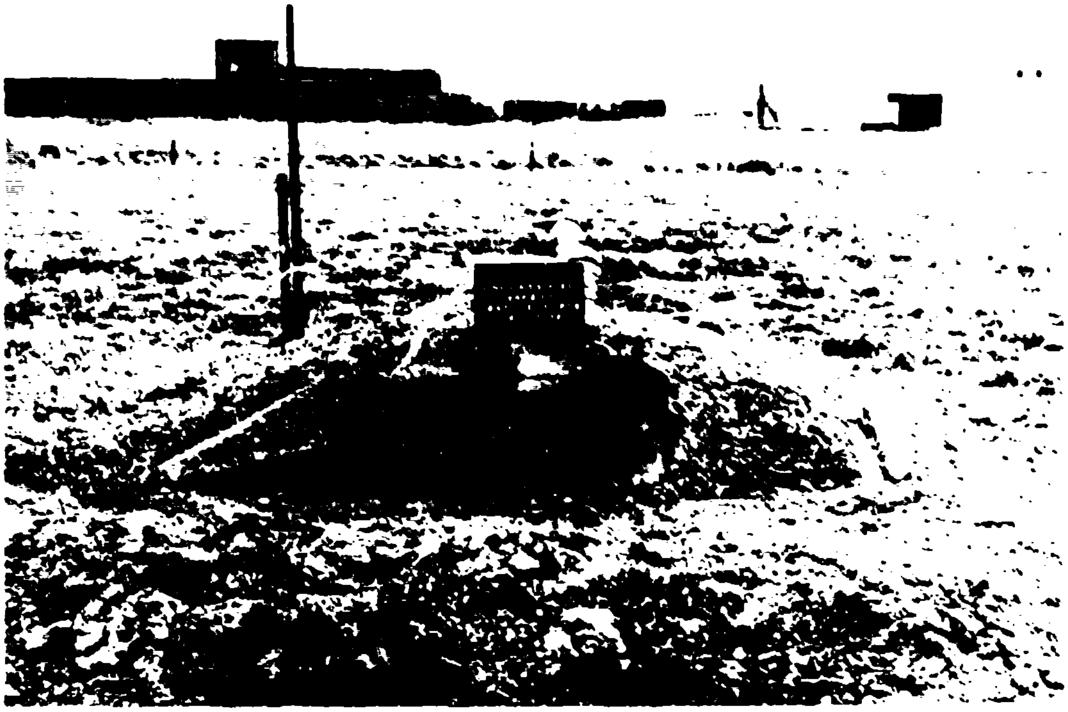


16. Donor charge on igloo base slab, without igloo structure.

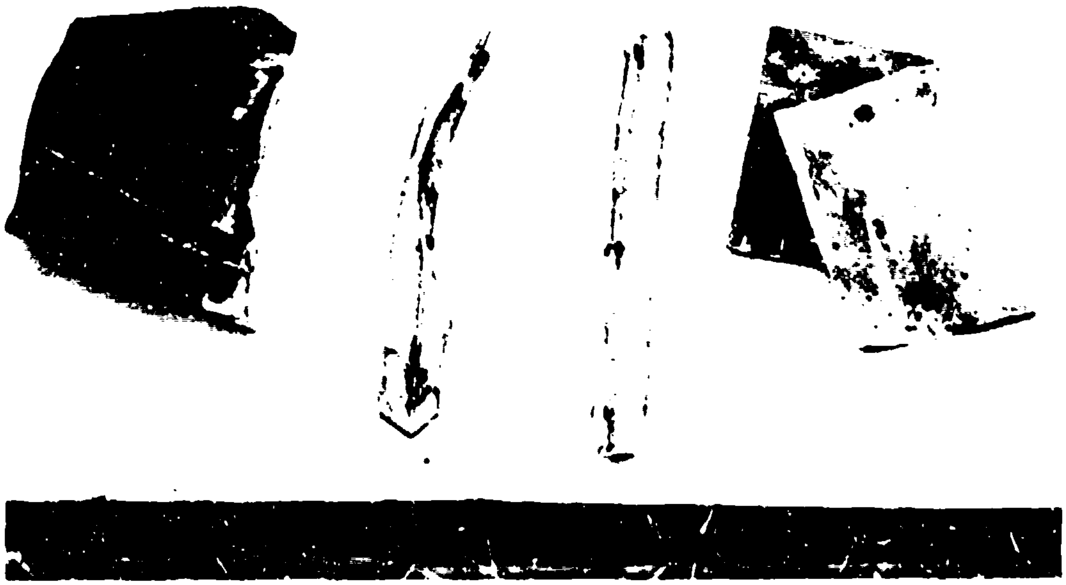


17. Acceptor A1 after firing.

17. Doors of acceptor A1 showing deformation.



18. Failure of headwall A2; rear wall is also damaged.



18. Doors of acceptor A2 after firing.

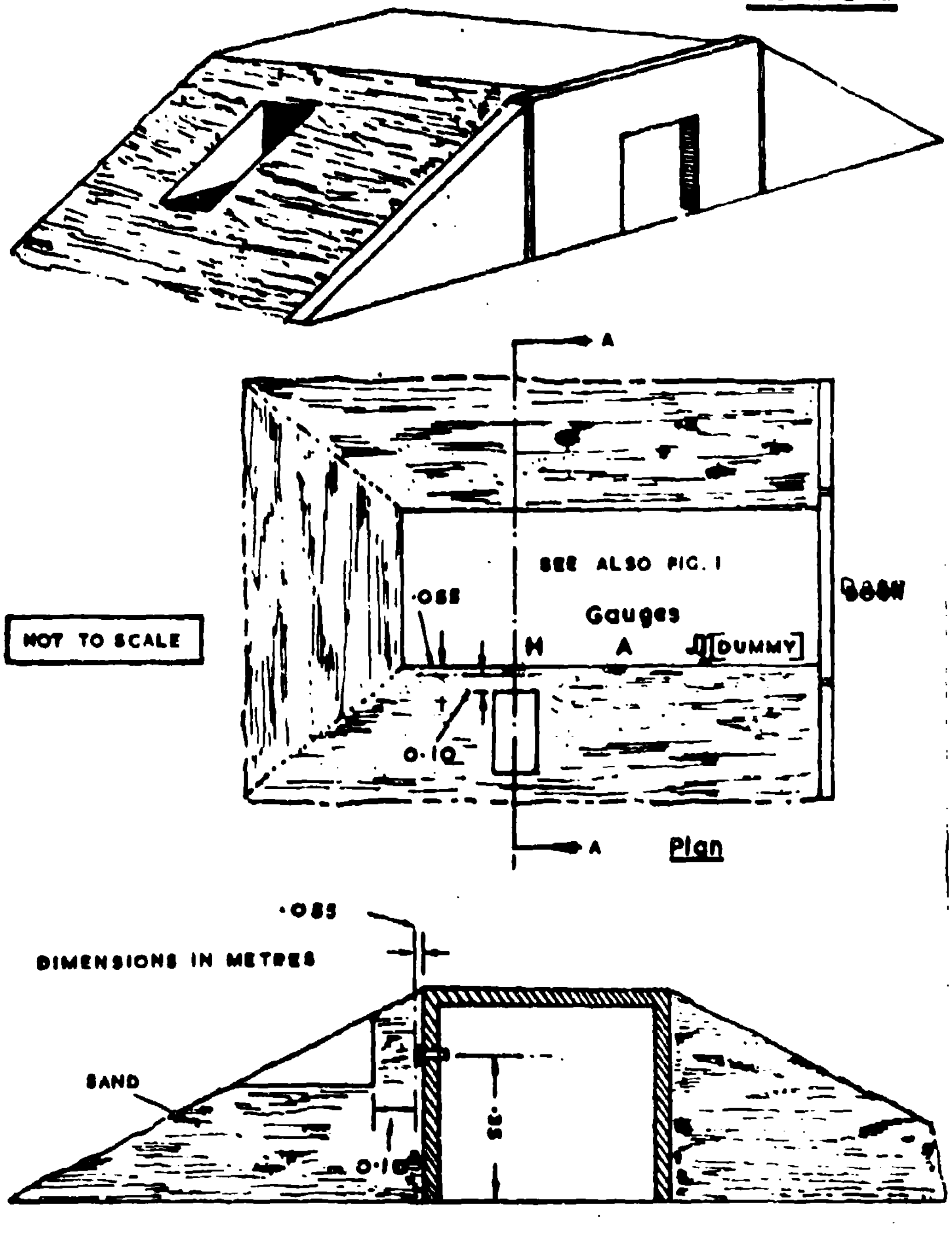
18. Doors of acceptor A5 after firing.

19. Cracked headwall of acceptor A5.

E S T C/3/71

SKETCH SHOWING OVERBURDEN ABOVE GAUGES A & H ON IGLOO I

Round 5



Section thro' A–A. View from door

FIGURE 20

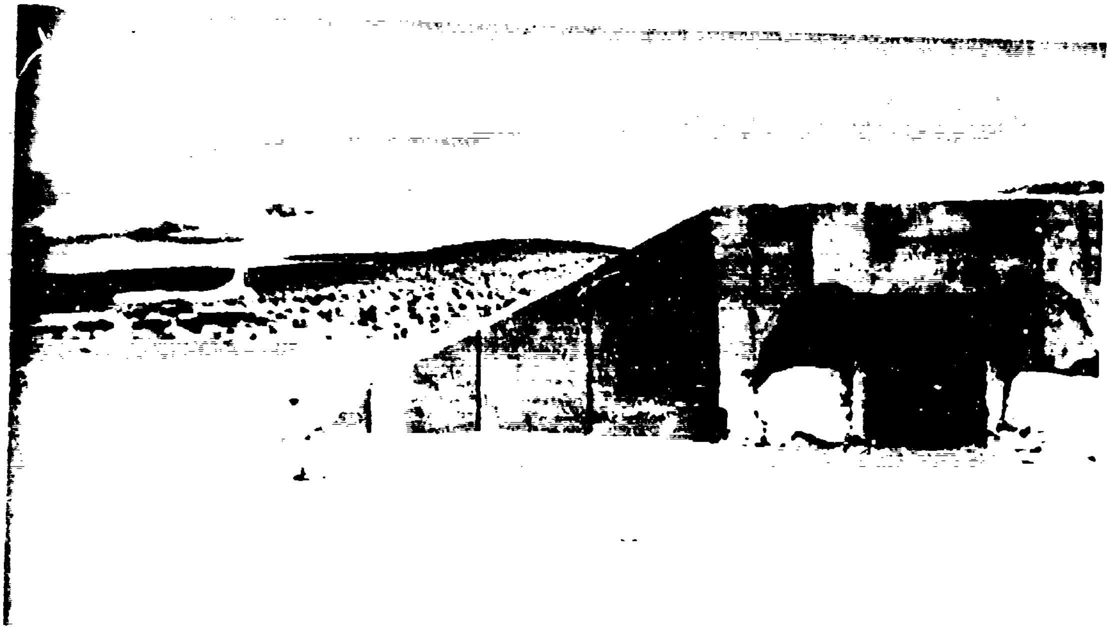
FIG. 21 Headwall of North Igloo. Note crack pattern approximating shape of steel arch.

Eskimo II

Failure of Headwall around Arch

FIGURE 22

Eskimo II
Severe Cracking of Headwall
FIGURE 23



Eskimo II
Heavy Damage to Headwall

FIGURE 24

DEVELOPMENT, DESIGN, AND TEST OF A NEW DOOR AND MAGAZINE ARCH FOR AN EXPLOSIVE LOADED STORAGE IGLOO

H. L. Callahan and W. V. Hill
Black & Veatch
Kansas City, Mo.

ABSTRACT

This report describes the development, design, and test of a new door and magazine arch for an explosive loaded storage igloo for increased blast loading. The door is of the sliding, single-leaf, and horizontal span type. Criteria required that the door meet the functional requirements of the using service, be efficient and easy to operate under all weather conditions, and be provided at the most economical cost. The arch is of steel multi-plate, with compound radii, to provide increased storage capacity along the side walls. The shape of the arch closely fits the concrete Stradley shape. Results of the Eskimo II test at the Naval Weapons Center, China Lake are included along with recommendations as to desirable design changes for the door and magazine arch.

INTRODUCTION

The Department of Defense has, for many years, been engaged in the development of safe and economical storage structures for explosive components of various weapons systems. The earth-mounded arch magazine, or igloo, is one of the more common types of storage structures which has been widely deployed. Several varieties of igloos have been constructed in the past as technologic, economic, and strategic developments brought about an evolution in their design. This evolutionary process has led to

standardization of igloo designs and the explosive quantity-safety distances which govern their adaptation to any given site.

The Office of the Chief of Engineers, in conjunction with the Department of Defense Explosives Safety Board, has been instrumental in the development of standard storage structures. Our firm has been associated with the Corps of Engineers in this development since 1946, and this report is on a door and magazine arch which are subject to adoption into the set of standard storage structures.

Empirical relationships play a major part in the design of structures to withstand impulses from high explosives, and for this reason, a lower level of confidence is placed on new, untested designs. Unlike the many protective structures which have been designed to resist the effects of nuclear explosions, explosive storage structures may be tested by simulating their actual design loads. In the case of the former, the Nuclear Atmospheric Test Ban precludes the verification of their design by testing. But fortunately, no such restriction on high-explosive testing exists, and the philosophy of design verification by testing has actually been used in the development of standard storage magazines. The catastrophic consequences which could result from inadequate design or construction warrant such tests.

The 1971 Eskimo I shot at the Naval Weapons Center in China Lake, California was such a test. The objective of the test was to confirm or refute the possibility of a secondary explosion within an acceptor magazine when a donor magazine loaded with 200,000 pounds was detonated at a scaled rear-to-front distance of 2 $W^{1/3}$. The test proved the design to be adequate.

This test was followed in May 1973 by the Eskimo II test which occurred at the same location, and upon which this report is based. The objective was similar to that of the previous test except that the explosive force was to simulate a donor magazine fully-loaded with 500,000 pounds.

The designs of the door and magazine arch are only covered in a general way in this report, for detailed design procedures are given in the referenced manuals.

DEVELOPMENT OF DOOR

The Eskimo I test proved that the weakest part of a magazine was the door. The test further revealed that increased safety could be gained through improved door design, with closer balance of strength between the door and the magazine. With a balanced design, magazines could be sited closer together with a saving in real estate costs.

After studying concept drawings of bi-parting sliding doors, two-leaf swing doors, single-leaf swing doors, and single-leaf sliding doors, it was found that a horizontal-spanning single-leaf sliding door was the most suitable. The study showed that all types of doors, except those with a single-leaf, required supports at the head and sill. Criteria had established that a smooth sill was required for satisfactory operation of a forklift truck handling large and hazardous objects. Many schemes were considered in the attempt to find a suitable support for the door at the sill. A slot or trench in the floor must have a movable bridge plate to permit vehicle movement through the door. The bridge plate requires that bearing surfaces be clean of dirt or sand each time it is put into place. Also, snow and ice accumulation in the floor slot

becomes a problem in opening the door during winter months. Removable or retractable stops in the floor were considered, but these also require an additional operation in opening or closing the door. There was also the problem that, after the door was closed, there was no way to see that the stops were in their proper position.

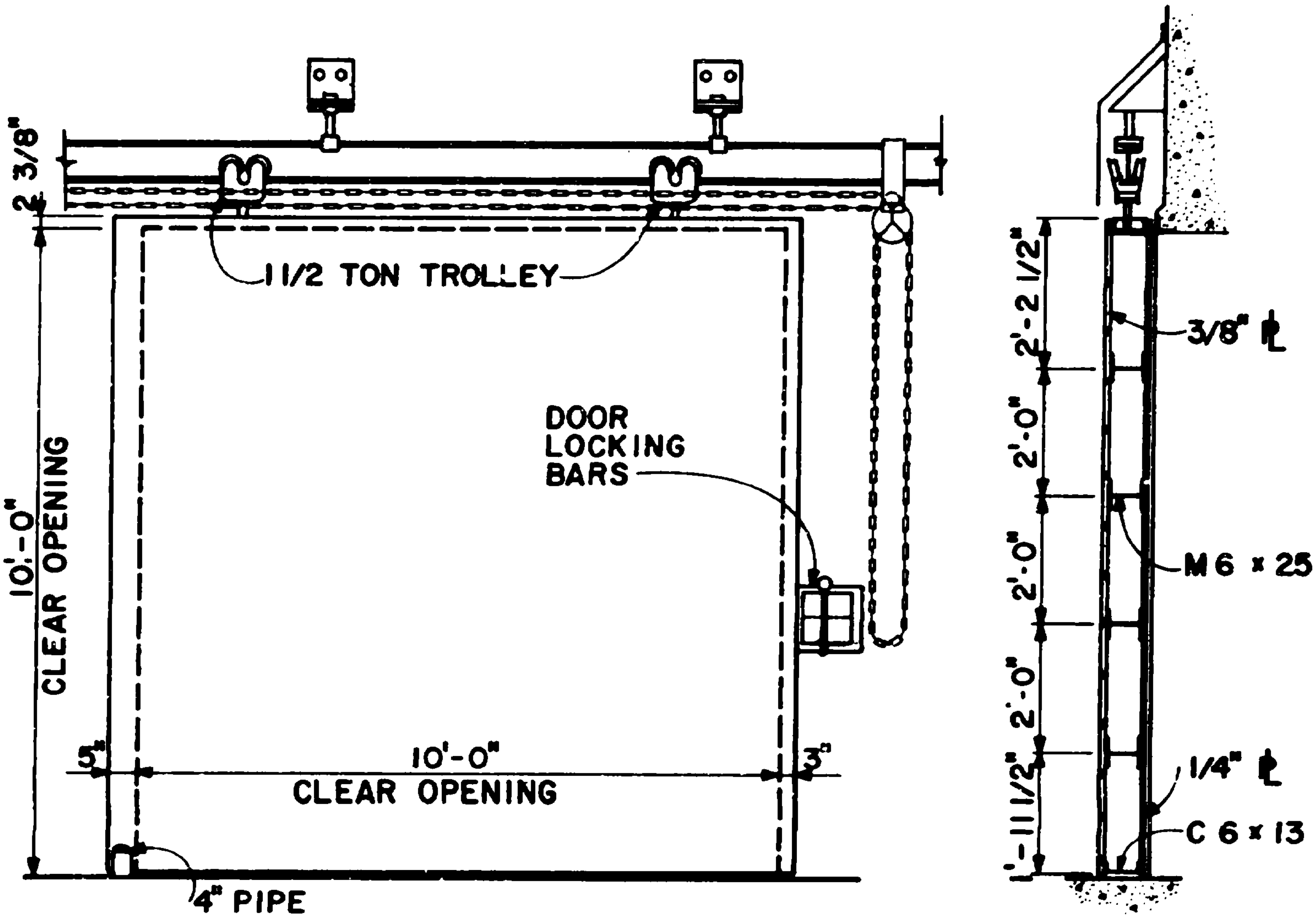
In order to have a sill free of all impedance, a horizontal spanning door was selected. The study also revealed that a single-leaf door was the most economical. A single-leaf swinging door would be difficult and dangerous to operate during periods of high wind velocity. The disadvantage of a sliding door is in making it weathertight, for the door must slide against the door seals. Another disadvantage of the horizontal spanning door is that the door jambs of the headwalls must carry 100 percent of the load.

After considering the functional requirements, that the door be easy to operate under all weather conditions, and forklift trucks could carry large objects over the sill safely, the single-leaf sliding door shown in Figure 1 was selected. This door is relatively easy to construct and economical. For the Eskimo II test, the chain operator and sheet metal hood were not installed.

DOOR DESIGN PROCEDURE

The door was designed by using the methods presented in TM 5-1300, "Structures to Resist the Effects of Accidental Explosions". Given data for design:

Maximum reflected pressure	=	100 psi
Impulse	=	1100 psi-ms
Duration of positive phase	=	50 ms
Maximum Deflection	=	18 inches



SINGLE LEAF SLIDING DOOR

FIGURE I

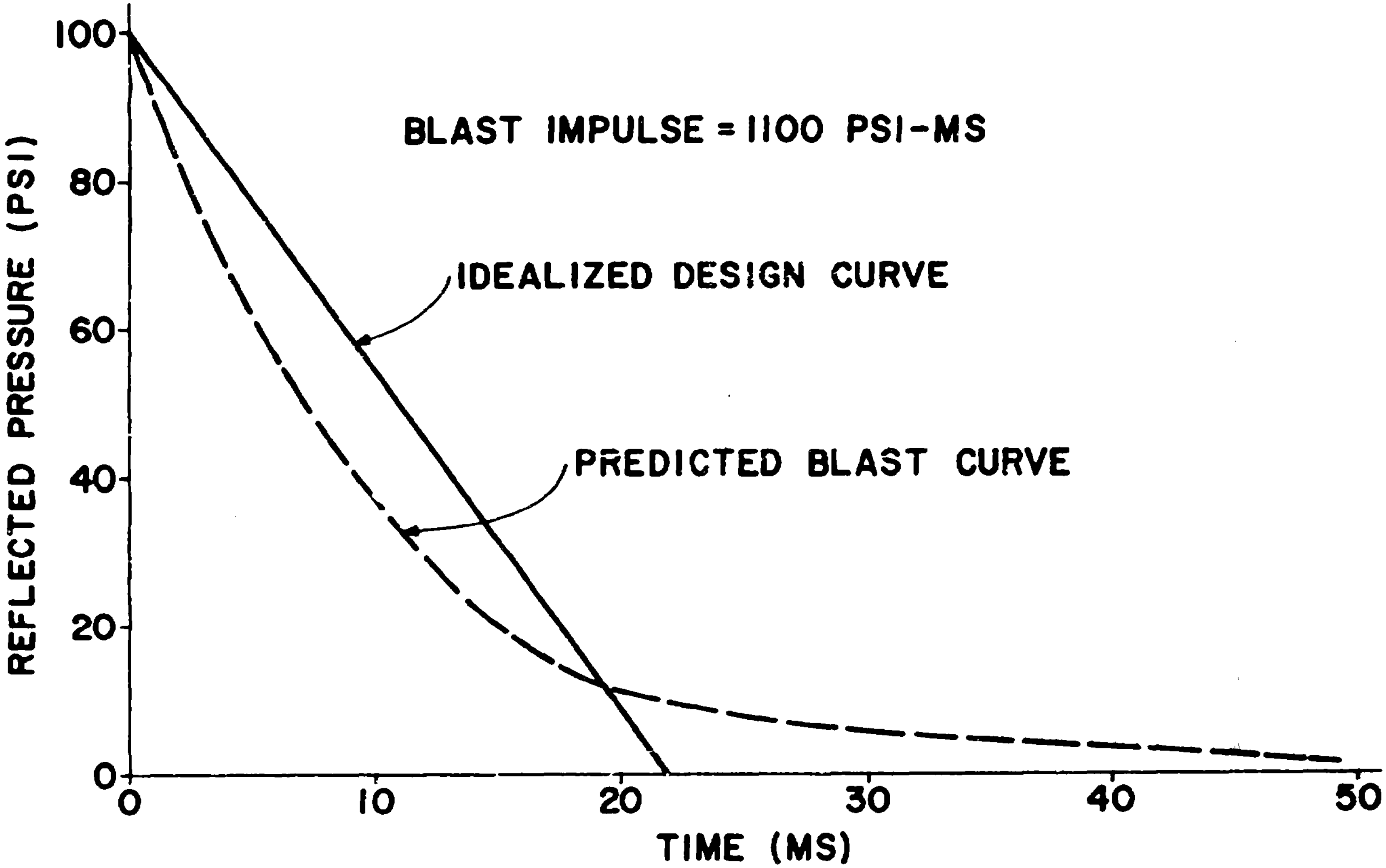
Step 1. Predict the pressure-time curve. This was done by using analog traces from the Kistler piezoelectric overpressure gages of the Eskimo I test. The Eskimo I test data obtained from gages mounted 147 feet from the donor center, facing the donor explosion, in the head-wall of an igloo, a few feet above the ground surface, are as follows:

1. Reflected peak overpressures, 72 to 76 psi.
2. Impulses, 641 to 705 psi-ms.
3. Duration of positive phase, 27.1 to 29.7 ms.

The predicted blast curve was plotted following the shape of the traces of the Eskimo I test, with the maximum reflected pressure equal to 100 psi, the impulse equal to 1100 psi-ms, and the duration of the positive phase equal to 50 ms. The predicted blast curve is shown in Figure 2.

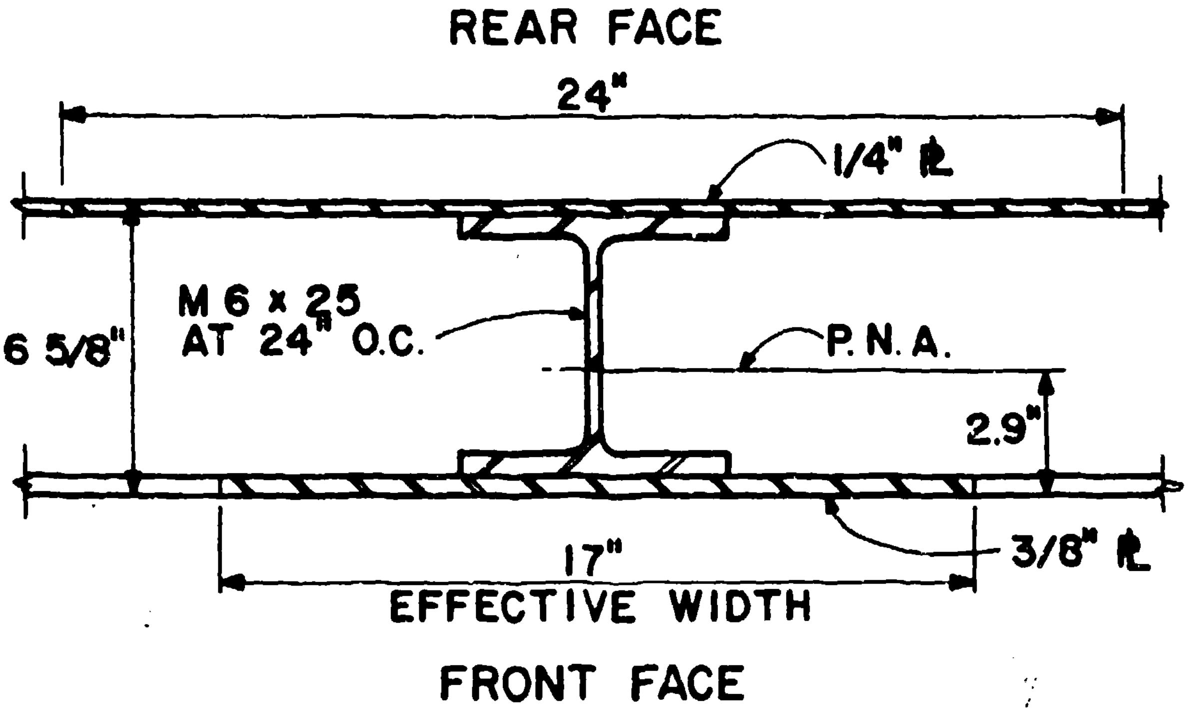
Step 2. The idealization of the load functions was depicted by plotting a straight line curve with the maximum reflected pressure equal to 100 psi and the triangular area signifying impulse equal to 1100 psi-ms. The idealized design curve is also shown in Figure 2.

Step 3. Determine door section. Many trial designs were performed using various combinations of beam sizes and spacings, with various plate thicknesses. The door section that proved to be the most economical had a 3/8-inch front plate, 1/4-inch back plate, and M6X22.5 beams on 2-foot centers. A check of producers and distributors of structural shapes revealed that M6X22.5 sections are available only on a special roll order of a minimum of 80 tons. M6X25 sections are not listed in the AISC "Manual of Steel Construction", but are readily available and were selected. The selected door section is shown in Figure 3.



IDEALIZATION OF PRESSURE-TIME FUNCTIONS

FIGURE 2



SPAN = 10' - 0"

WEIGHT = 760 LBS

MATERIAL A 36 STEEL

DYNAMIC YIELD STRENGTH = 46,800 PSI

I, MOMENT OF INERTIA = 170.5"^{4}

Z, PLASTIC SECTION MODULUS = 42.7"^{3}

DOOR SECTION

FIGURE 3

The weight of the selected door section is 38 pounds per square foot compared to the Stradley door, OCE Drawing Number 33-15-61, weight of 44 pounds per square foot. The new door also has greater resistance to blast loads than the Stradley door.

Step 4. Properties of the door section were determined by conventional methods. The effective width of the front plate was calculated by using the design procedures given in, "Light Gage Cold-Formed Steel Design Manual", American Iron and Steel Institute. The properties of the door section are shown in Figure 3.

Step 5. Dynamic design parameters. Using TM 5-1300, "Structures to Resist the Effects of Accidental Explosions", the values shown in Figure 4 were calculated. T_n is the effective natural period of vibration, calculated from the effective unit mass and the equivalent unit stiffness of the system. The maximum deflection is 14.9 inches, which is acceptable, for the allowable was 18 inches.

DEVELOPMENT OF MAGAZINE ARCH

A magazine was required for the storage of weapons packed in large shipping containers. A study of presently designed storage magazines was made to see if one would meet the requirements. It was found that the Stradley Magazine, OCE Drawing No. 33-15-71, designed in 1959, would meet the requirements. The interior walls of the Stradley arch are vertical up to the spring line which is 8 feet above the floor. The disadvantage of the Stradley Magazine is the construction cost. It is concrete and has 3 exterior and 5 interior radii which require costly form work. Steel arches are more economical,

TM 5-1300

STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS

T_n NATURAL PERIOD = 15 MS

r_u RESISTANCE = 46.3 PSI

X_E ELASTIC DEFLECTION = 0.58"

$$\frac{X_m}{X_E}\ \frac{\text{MAXIMUM DEFLECTION}}{\text{ELASTIC DEFLECTION}} = 25.5$$

X_m MAXIMUM DEFLECTION = 14.9"

T_m TIME OF MAX. DEFLECTION = 25 MS

FIGURE 4

and have been proven to perform well under high explosive blast loadings. The OCE steel arch, Drawing No. AW-33-15-64, was found to be unsatisfactory for storing a large number of the weapons because of the low headroom near the sidewalls. A study was made to develop a steel arch with a shape similar to the Stradley. It was found that ARMCO Steel Corporation's Super-Span, high profile arch met the requirements. Figure 5 shows the size-comparison between the AW-33-15-64 steel arch and the new steel Stradley.

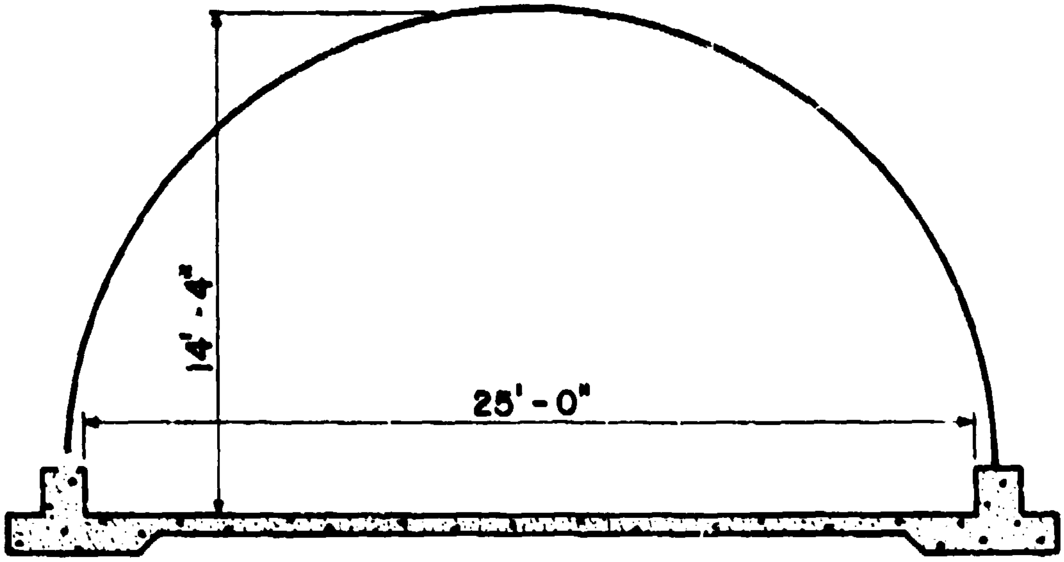
By virtue of its nearly vertical sidewalls, the new steel Stradley has approximately 20 percent more storage capacity while requiring only 6 percent more steel plate. The two arches occupy equal amounts of area, so neither possesses an advantage in real estate costs.

ARCH DESIGN PROCEDURE

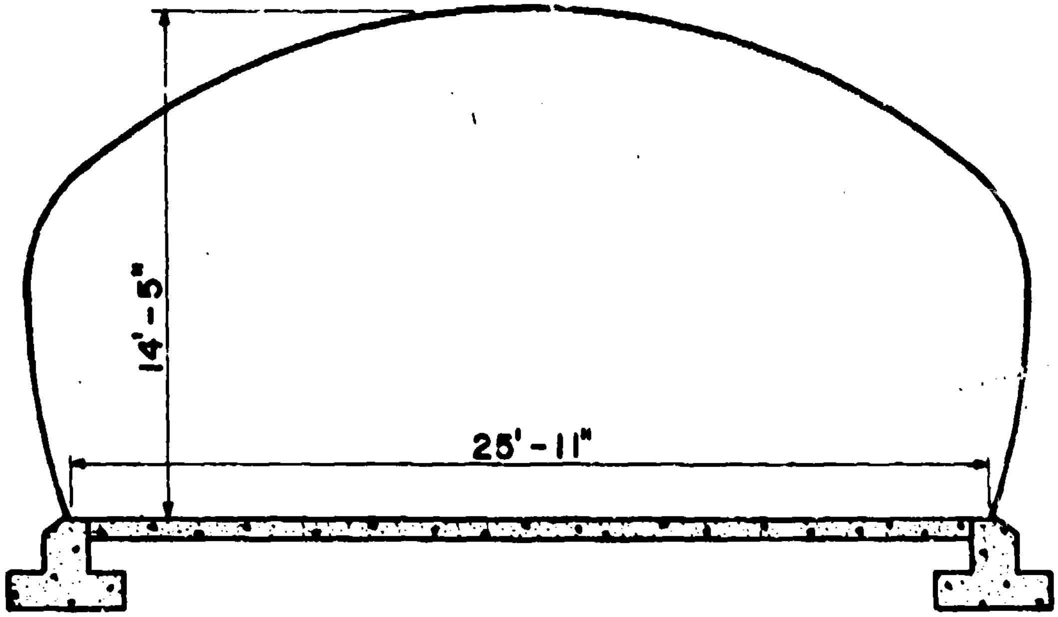
The steel arch was designed by using the methods presented in EM 1110-345-420, "Design of Structures to Resist the Effects of Atomic Weapons - Arches and Domes." The size and shape of the arch and the supports are illustrated in Figure 6.

The roof portion of the arch encompassing a central angle of 80° was assumed to have fixed ends at the conrete thrust beams. No attenuation of the blast pressure or impulse by the earth cover was assumed. Given data for design:

Incident peak overpressure	=	40 psi.
Impulse	=	1100 psi-ms.
Duration of positive phase	=	80 ms.



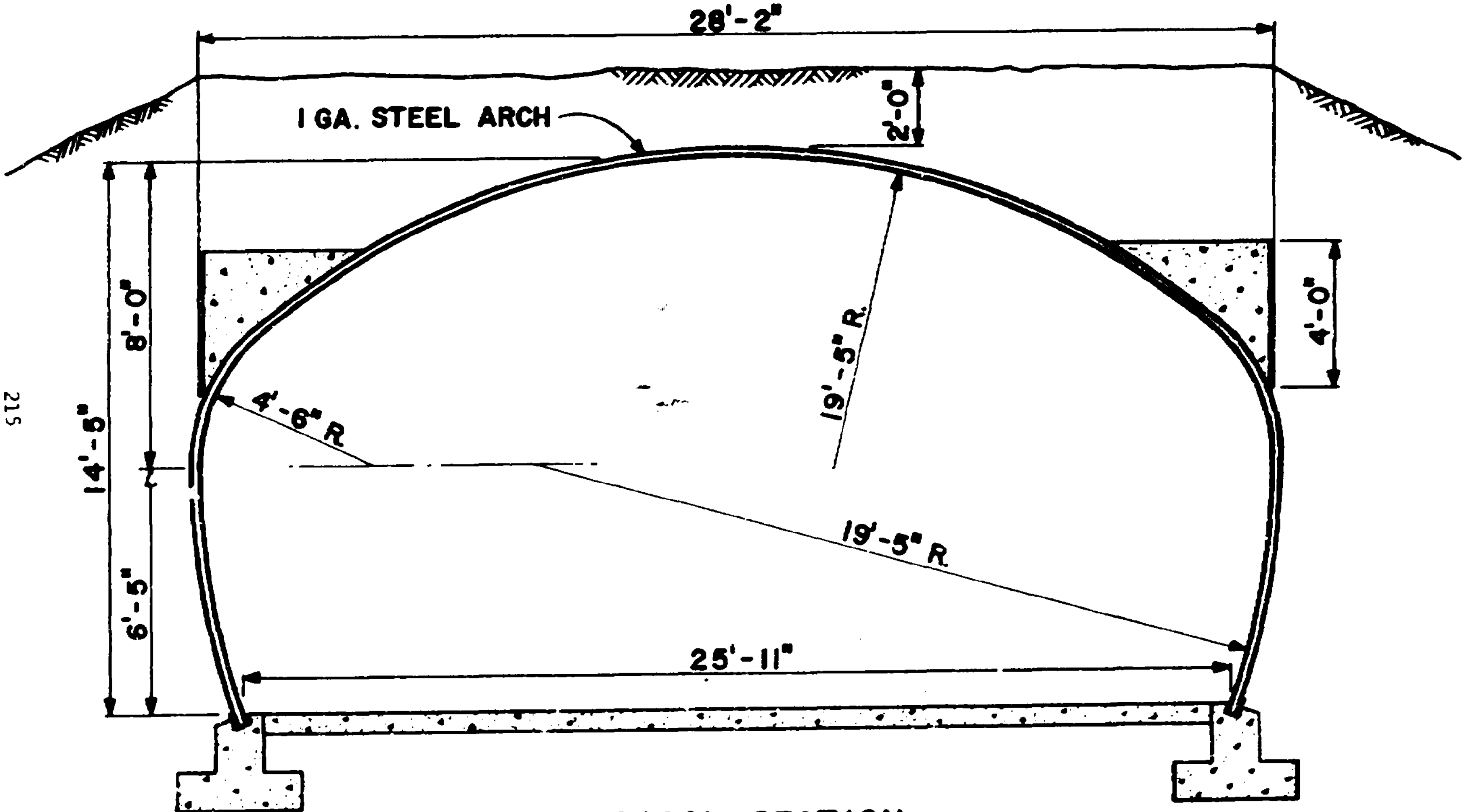
AW 33-15-64



NEW STEEL STRADLEY

SIZE COMPARISON

FIGURE 5



TYPICAL SECTION

FIGURE 6

Step 1. Determine the properties of the arch. This was done by using the design procedures given in the American Iron and Steel Institute's, "Handbook of Steel Drainage & Highway Construction Products". The arch properties are shown in Figure 7. The ultimate dynamic buckling stresses are for steel with a minimum yield strength of 33,000 psi and backfill compacted to 85 percent Standard AASHO density.

Step 2. Determine the compression and deflection mode loadings. With blast loads from high explosive, the shape of the curve is not important. This is because the blast pressure has reached the negative phase before the arch has reached its maximum deflection. The design of the arch is controlled by the impulse.

The compression mode curve was depicted by a straight line with the peak pressure equal to 40 psi and the triangular area representing impulse equal to 1100 psi-ms. The deflection mode impulse was found from the formula:

$$I = 1.25 \; Pso \; t_s$$

where Pso is the incident peak overpressure, and t_s is the transit time of the shock wave. Using a shock front velocity of 2200 feet per second and a structure width of 28 feet, the transit time is equal to 12.8 ms.

The peak deflection pressure is equal to the incident peak overpressure and occurs when the shock wave reaches the crown of the arch. The compression and deflection mode loadings are shown in Figure 8.

Step 3. Determine the arch's resistance to compression and deflection mode loadings. The compression mode resistance was calculated using the ultimate dynamic buckling stress of 42,900 psi in the arch.

HANDBOOK OF STEEL DRAINAGE & HIGHWAY CONSTRUCTION PRODUCTS

1 GAGE MULTI - PLATE

6" x 2" CORRUGATION

WEIGHT = 11.25 PSF

MOMENT OF INERTIA = 1.99"^{4}/FT

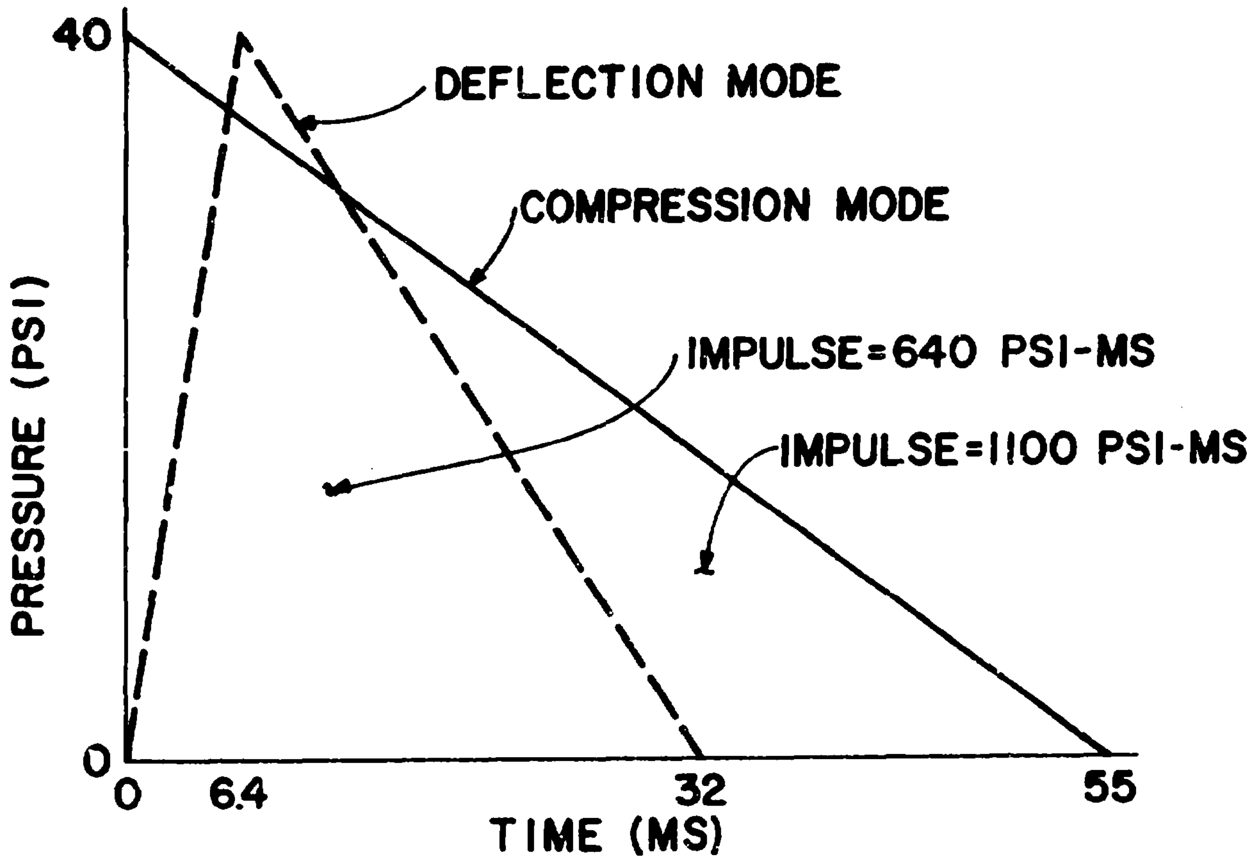
SECTION MODULUS = 1.75"^{3}/FT

ULTIMATE DYNAMIC BUCKLING STRESSES

WITH THRUST BEAMS = 42,900 PSI

WITHOUT THRUST BEAMS = 11,000 PSI

FIGURE 7



COMPRESSION AND DEFLECTION MODE LOADINGS

FIGURE 8

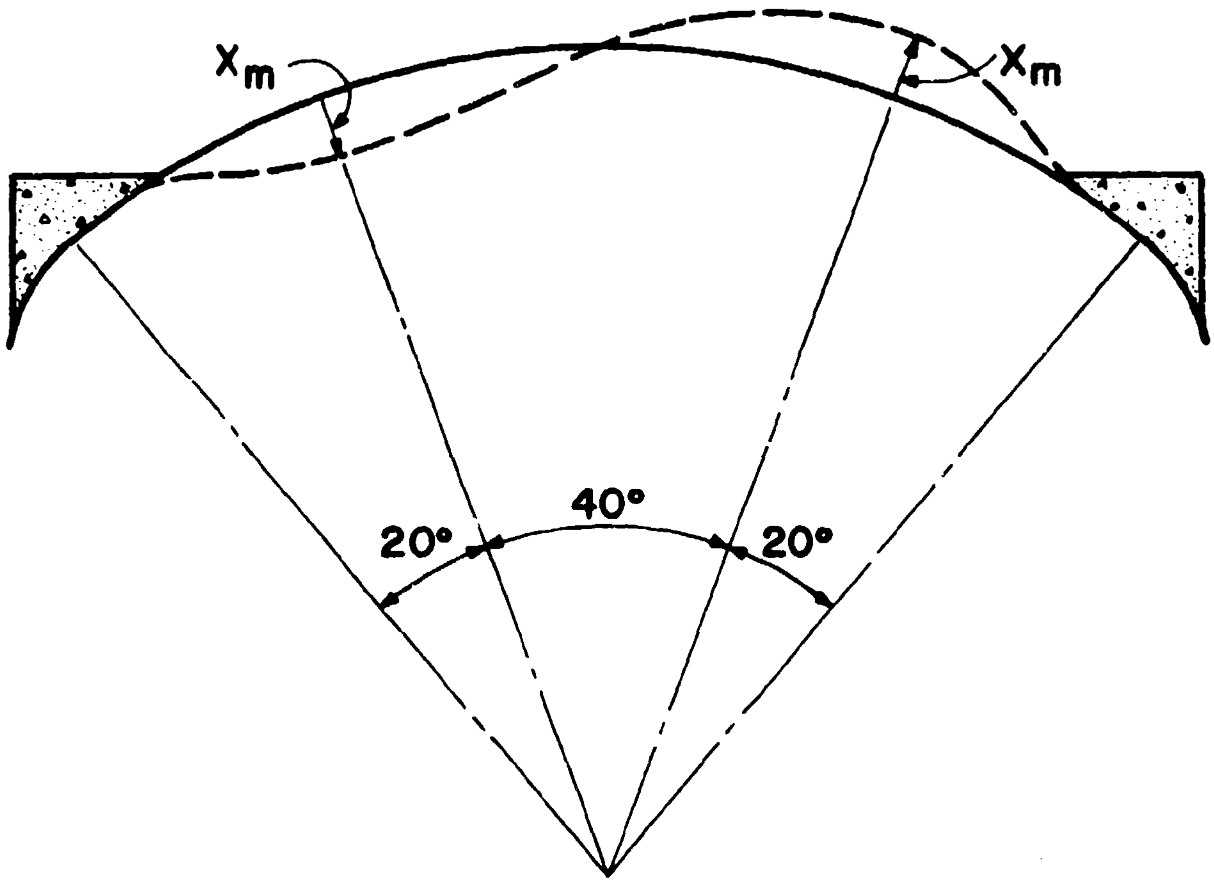
The resistance in the deflection mode is obtained by equating the deflection mode moment, in terms of the yield resistance, to the resisting moment available for blast loading.

In order to evaluate the available resisting moment of the section, it is necessary to know the axial thrust in the arch. This thrust is dependent upon the average value of the compression mode loading on the arch over the time required to reach maximum deflection. Determining the average value of the compression mode loading is a trial and error process.

For the arch design, an average value of 5 psi was assumed for the compression mode loading. The average value of 5 psi for the compression mode loading gives a deflection mode loading resistance of 3.5 psi.

Step 4. Compute the natural period of the arch in the compression and deflection modes. In determining the mass, an average weight of 400 pounds per square foot of earth cover was used. The time of the natural period T_n in the compression mode loading is 48 ms. The time of the natural period T_{nd} in the deflection mode loading is 453 ms.

Step 5. Determine the time to reach maximum deflection and the ratio of maximum deflection to elastic deflection. These values are shown in Figure 9. The ratio of maximum deflection to elastic deflection is 4.1, which is less than the allowable of 10 for concrete arches and less than the higher allowable for steel arches.



MAXIMUM DEFLECTION = 4.1 X_E

T_m TIME OF MAX. DEFLECTION = 231 MS

COMBINED MODE LOADINGS

FIGURE 9

Step 6. Calculate the average compression mode pressure over the time to reach maximum deflection. This is equal to the impulse divided by the time of maximum deflection, which results in an average compression mode pressure of 4.8 psi. The assumed value in Step 3 was 5.0 psi. This means that the resistance available for blast loading is more than the 3.5 psi obtained in Step 3, and the design is satisfactory.

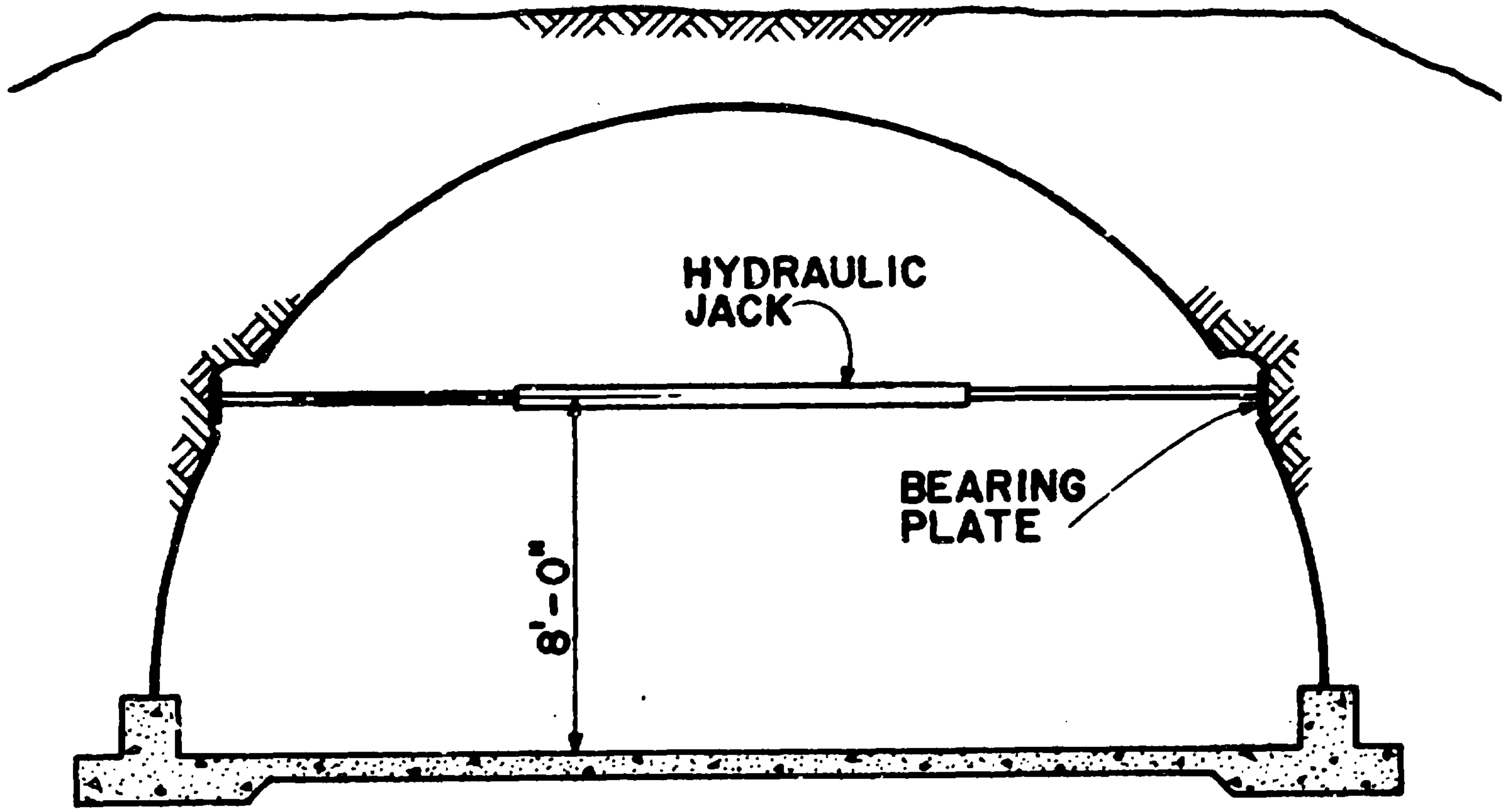
Step 7. Design thrust beams. A key feature of the Super-Span concept is the concrete thrust beams that are added to the assembled structure during backfilling, see Figure 6. These triangular elements are locked to the corrugated plates by means of hook bolts attached to the plates and cast into the concrete. There is a thrust beam on each side of the top arch, and each of them is positioned at the junction of the arch and the side wall. The thrust beam provides a vertical surface against which effective soil compaction is easily obtained. The thrust beam transfers the thrust in the top arch into the well-compacted soil against its vertical face. The arch configuration is such that the magnitude of deflection in the arch is greatly influenced by the stabilizing effect of the surrounding earth fill. Therefore, a test was conducted to determine the horizontal modulus of soil reaction. The test was conducted by the personnel at China Lake and was performed at an existing igloo constructed for the Eskimo I test. The fill surrounding the arch had been compacted to 90 percent density and was classified as SM, silty sand, well-graded, non-plastic, with an in-place density of 120 pounds per square foot.

The test involved the jacking of 10-inch diameter plates horizontally through holes cut in the sides of the arch, as shown in Figure 10. Because the capacity of the largest hydraulic jack available was 24,000 pounds, it was estimated that 10 inches was the maximum size of bearing plates that could be used. The bearing plates were placed at locations corresponding to the locations of the thrust beams. Load increments of 2000 pounds were applied by the hydraulic jack. Deflection readings were measured by a dial micrometer at each bearing plate. With each increment of load, an initial deflection reading was taken immediately. The load was allowed to set at each increment for 5 minutes before the final reading was taken. Because the blast load is suddenly applied, the initial deflections were used to design the thrust beams. Results of the test are shown in Figure 11. The variance between the left and right sides of the arch probably resulted from a lack of uniform backfill treatment.

The thrust beams were designed to develop the ultimate dynamic buckling stress in the arch. The arch produced a maximum horizontal thrust of 11,200 pounds per inch. A 48-inch deep thrust beam was used, resulting in a horizontal soil bearing pressure of 233 psi. From Figure 11, using a load of 233 psi, the average deflection of the thrust beams is 0.7 inch. The deflection of the crown of the arch, due to displacement of the thrust beams, is 1.4 inches downward.

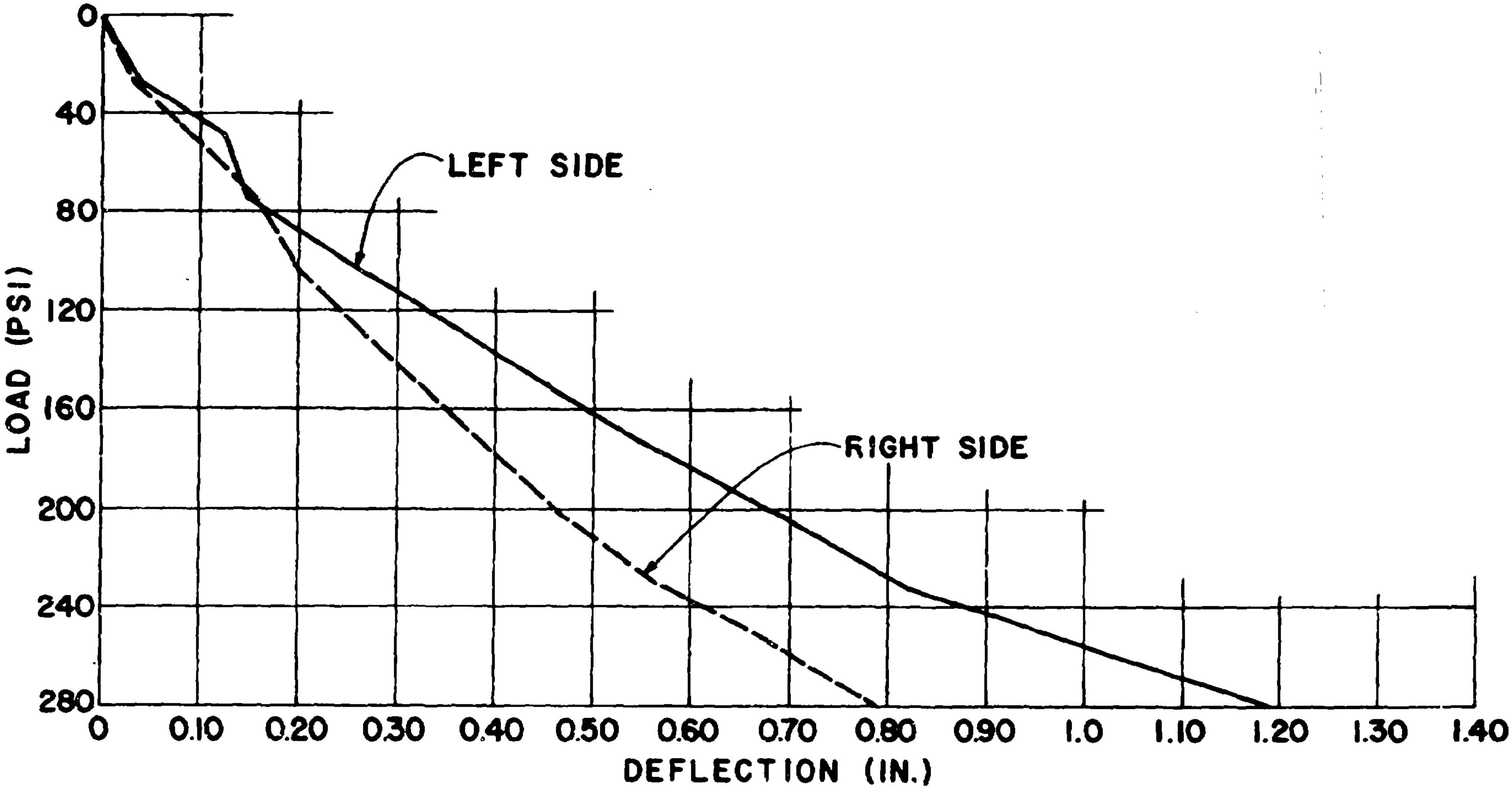
TEST OF DOOR

Figure 12 shows the door mounted on a headwall built in accordance with OCE Drawing No. AW 33-15-64. This headwall, referred to as the SAC type,



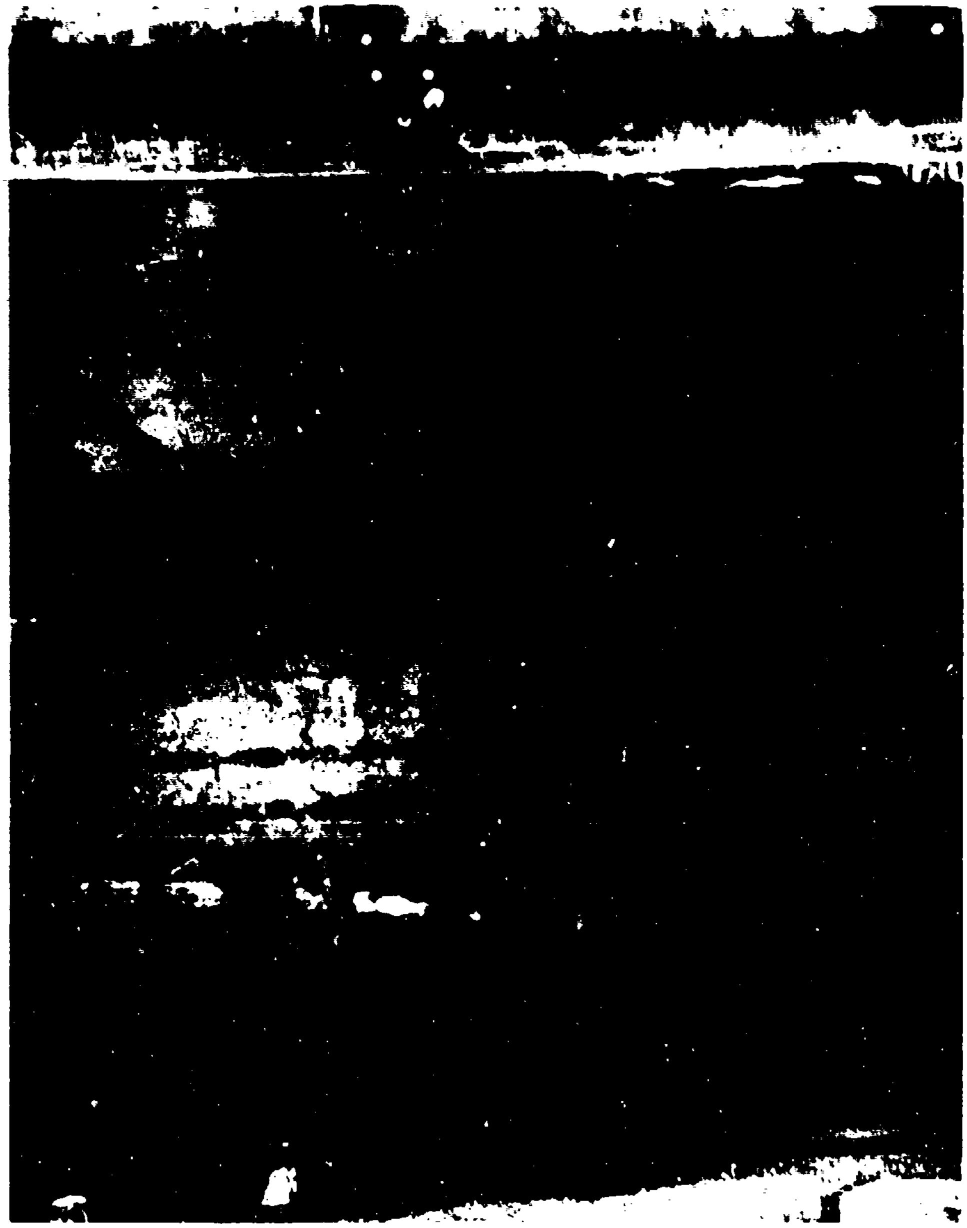
MODULUS OF SOIL REACTION TEST

FIGURE 10



MODULUS OF SOIL REACTION CURVES

FIGURE 11



EXTERIOR VIEW OF DOOR
FIGURE 12

was used in the Eskimo I test. The headwall was a 12-inch concrete wall with reinforcing each way in each face. All reinforcing was No. 4 at 12-inch centers, except for the vertical bars in the rear face which were No. 6 at 12-inch centers.

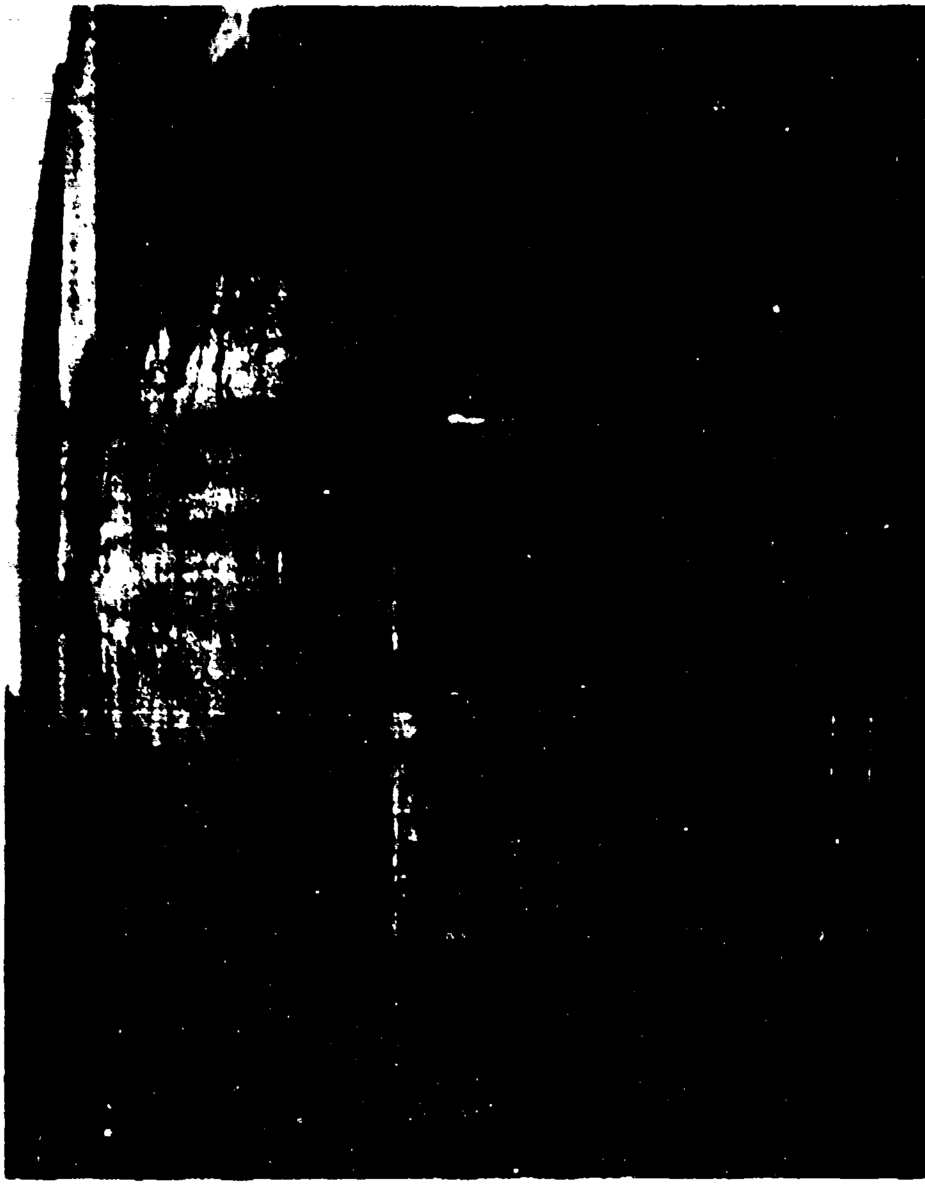
After the assessment of damage to the headwall from the Eskimo I test, there was concern as to the ability of the headwall to support the new door, since the new door spans horizontally and the blast loading for the Eskimo II test was to be greater.

Figure 13 is another view of the completed door.

Figure 14 shows the restraining bracket and pin used to hold the door in the closed position during the time of an accidental explosion.

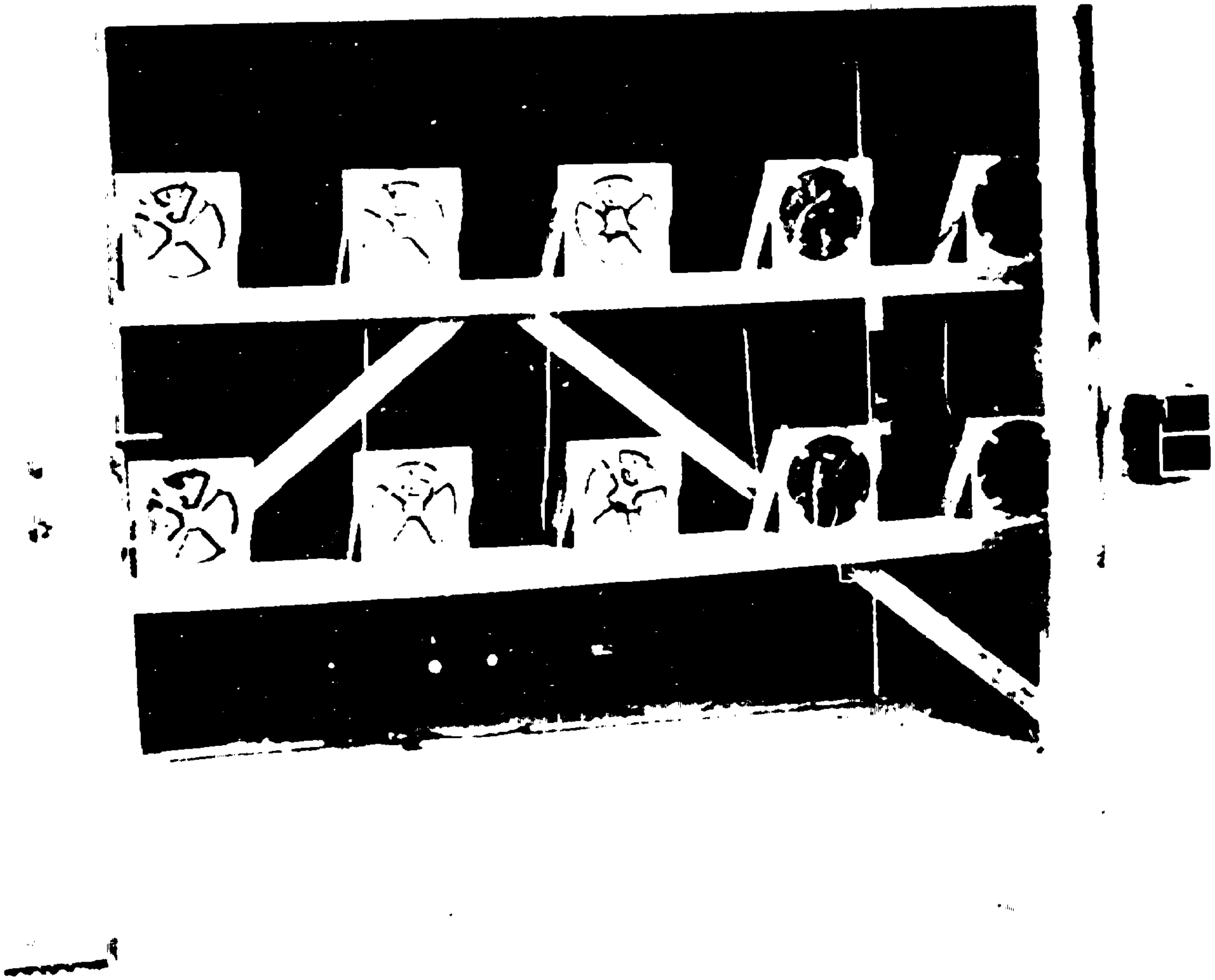
Figure 15 is a view of the acceptor charges. Twelve M15 land mines were used as acceptor charges. These land mines were positioned in two rows of six, one approximately three feet from the floor and one row approximately six feet above the floor. The land mines were secured on their edges on trays so that the bottom surface of each mine was vertical and accessible to possible headwall and door fragments. In each row there was one mine on each end that was opposite the concrete headwall of the magazine, and the trays were so positioned that the acceptor explosives were approximately three feet from the plane of the inside surface of the headwall.

Figure 16 is a view of the headwall after the test. The blast loading of the Eskimo II test was somewhat higher than the loading for which the door was designed. The reflected blast pressure recorded at the headwall



DOOR IN PLACE
FIGURE 13

DOOR RESTRAINING BRACKET
FIGURE 14



ACCEPTOR LAND MINES IN PLACE
FIGURE 15

HEADWALL AFTER TEST
FIGURE 16

was 310 psi and the impulse was 2,210 psi-ms. These values are based on preliminary and approximate means of data reduction; and the final data are not yet available. Essentially all of the headwall adjoining the interior magazines, that part of the headwall inside the archline, was destroyed. The acceptor land mines were somewhat damaged but no burning occurred.

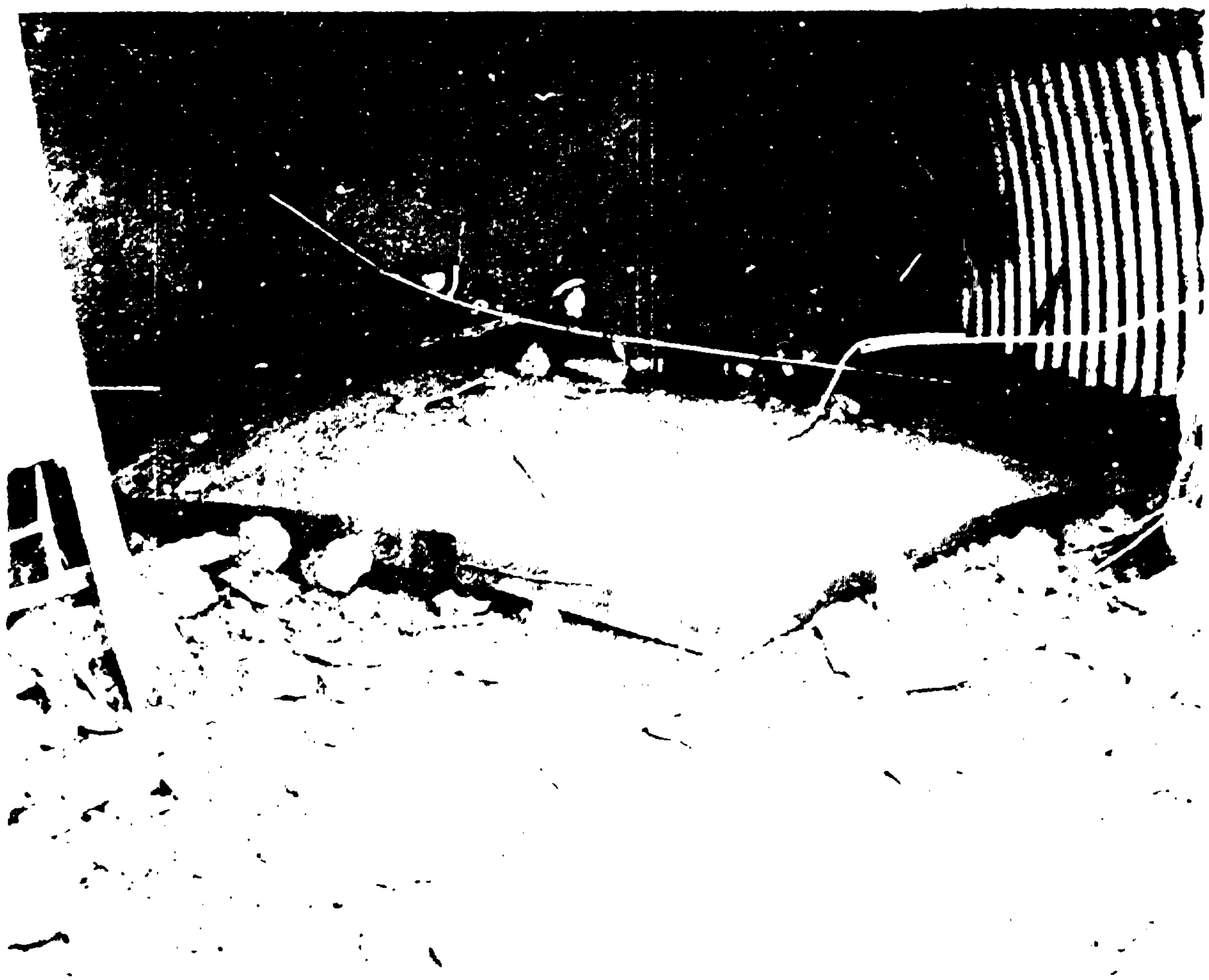
Figure 17 is an interior view of the headwall and door frame after the test. Figure 18 shows the door after the test, laying on its exterior face with the bottom of the door adjacent to the rear wall of the igloo. It is probable that the headwall failed first at the floor line allowing the bottom of the door to be blown inward, and as the rest of the headwall failed, the door continued to move inward breaking the door hanger rods.

Figure 19 shows the deflection of the door. It is assumed that the headwall had deflected 4-1/2 inches at the midheight of the door before the headwall failed at the floor line. This allowed the door to deflect 4-1/2 inches at the jambs. In the horizontal direction, the door deflected 10 inches. The horizontal deflection would have been larger had the concrete headwall been able to continuously support the door.

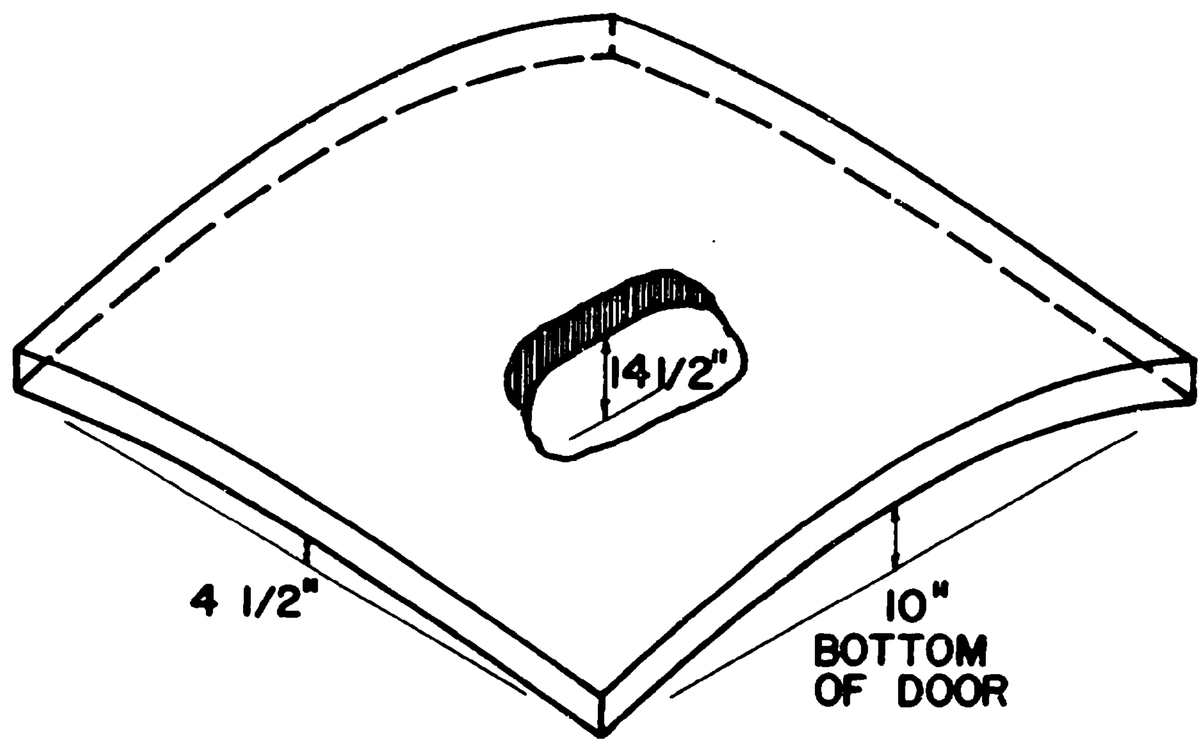
RECOMMENDED REVISIONS TO DOOR

In order to keep the door from being blown through the opening in the headwall, as the headwall and door deflects, it is recommended that the edge bearing of the door be increased one inch at the head and jambs. This will increase the width of the door by two inches and the height by one

INTERIOR VIEW OF HEADWALL
FIGURE 17



DOOR AFTER TEST
FIGURE 18



DOOR DEFLECTION

FIGURE 19

inch. In order to provide more support to the top of the door for blast loading, the hanger rods, between the trolleys and the top of the door, should be changed to high-strength bolts, ASTM A354, Grade BB. It is also recommeded that the door be mounted on a modified Stradley headwall. The Stradley headwall has pilasters on each side of the door opening to support the door during the time of an accidental explosion.

At the present time, a new headwall is being designed for the higher blast loads, a maximum reflected pressure of 100 psi, and an impulse of 1100 psi-ms. The new headwall will have pilasters at the door jambs. One other feautre is being added to the door, a retainer to keep the door in place for 100 ms, after the arrival of the positive blast load. The retainer is to restrain the door during the rebound and negative phase. This is to protect the magazine from the fire ball generated by an accidental explosion.

TEST OF MAGAZINE ARCH

For the Eskimo II test, a magazine 80 feet long was constructed. During the Eskimo II test, the blast wave approached along the arch axis; this caused compression mode loading only in the arch. The data from the pressure gage, planned to record incident overpressures, are presently not available. The reflected blast pressure recorded at the headwall was 252 psi and the impulse was 1750 psi. These values are also based on preliminary data and are somewhat higher than that for which the arch was designed.

Before and after the test, measurements were made between points on the center line of the floor and various points on the arch. The relative movements between the floor and arch are shown in Figure 20. The measurements were made at 20, 40, and 60 feet from the magazine headwall.

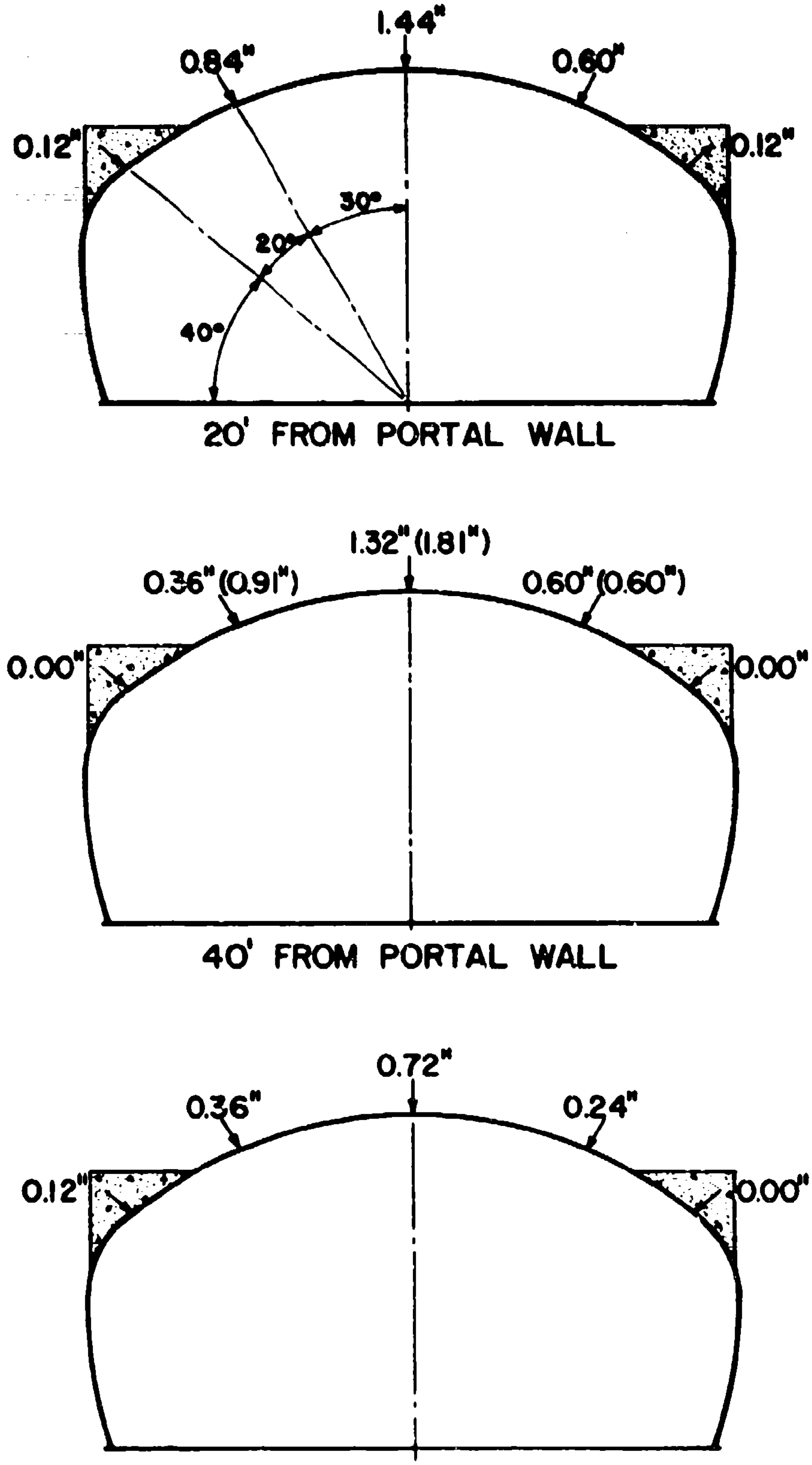
The direction of the arrows indicates the direction of change in the measured distance. The only distance to increase was at 20 feet from the headwall and at the right thrust beam.

Scratch gages were installed in the plane of the arch 40 feet from the headwall to register maximum displacements. These maximum displacements were also between the center line of the floor and the points on the arch shown in parentheses on Figure 20. The distortion of the arch was not discernible from visual inspection, and the measured values are well within the acceptable limits.

RECOMMENDED REVISIONS TO ARCH

Pending results of the proposed Eskimo III test, no revision to the arch is recommended. During the Eskimo III side-on loading test, the blast wave will be approaching normal to the arch axis. This will load the arch in both the compression and deflection modes.

The arch was designed to be used as a standard magazine, with the thrust beams being sized for all classifications of backfill material, except those containing organic materials. Soil classified in Military Standard MIL-STD-619 as CH, which is common at many sites, has a subgrade modulus of 50 to 100. The backfill at China Lake is excellent material and is classified



DISTORTIONS OF ARCH

FIGURE 20

as SM, which has a subgrade modulus of 200 to 300. Had the backfill material used in the Eskimo II test been classified as CH, the deflection probability would have been three to four times greater.

Pending results of the proposed Eskimo III test, it may be possible to reduce the size of the thrust beams when select material is available and specified for backfill.

NEW DESIGN CONCEPTS FOR MUNITION STORAGE MAGAZINES

By

Charles N. Kingery

ABSTRACT

This report describes some new approaches and design concepts for application to the hardening of munition storage magazines in order to reduce safe separation distances. Extension of the earth cover around the front of the magazine, the use of a tunnel entranceway with two doors, as well as a new door design are presented for consideration. It should be possible to cut the present safe separation distance for face-to-face orientation by a factor of 3.

I. INTRODUCTION

The purpose of this report is to present some new ideas and concepts for hardening munition storage magazines in order to reduce established safe separation distances.

A. Background

The vulnerability of munition storage magazines or igloos to blast and fragment damage from donor magazines has been a subject of concern to the Department of Defense for many years. In recent years the Department of Defense Explosive Safety Board (DDESB) has been engaged in a program to determine more accurately the minimum safe separation distances between munition storage magazines. The minimum safe separation distance is defined as the smallest distance that will provide assurance that an explosion in one magazine (donor) will not propagate to another (acceptor), although the acceptor magazine and possibly its contents, might be extensively damaged. The ESKIMO I test conducted in December 1971 and ESKIMO II test conducted in May 1973 were both designed to establish new minimum safe separation distances for explosives quantity-distance criteria in the U.S. and NATO countries. ESKIMO I was successful in meeting this objective while the results from ESKIMO II have not been published yet.

B. Objective

The objective of this report is to take a critical look at the present designs and determine some suggested modifications that might reduce the established safe separation distances. The major areas of interest are 1, the reduction of the production of blast and fragments from the doner in the direction of the door and headwall due to an internal explosion and 2, the reduction of blast and fragment loading on the exterior of the door and headwall of the acceptor due to an external explosion.

C. Present Design Concept

The present design is presented in Figure 1. Only the exterior profile is shown in the sketch. This is the type of structure exposed on ESKIMO I and ESKIMO II.

The slope of the earth cover is a 1:2 or an angle of 26° 34' from the horizontal. The interior of the test igloos consist of a steel arch 14 feet high and 25 feet wide at the floor. The igloos were covered with compacted earth to a 2 foot depth at the top of the arch.

The primary objective of these tests were to evaluate the safe separation distance by hardening the headwall and door designs. Based on the results of these tests it appears that the most vulnerable parts of the igloo are still the headwall and entrance door. This has also

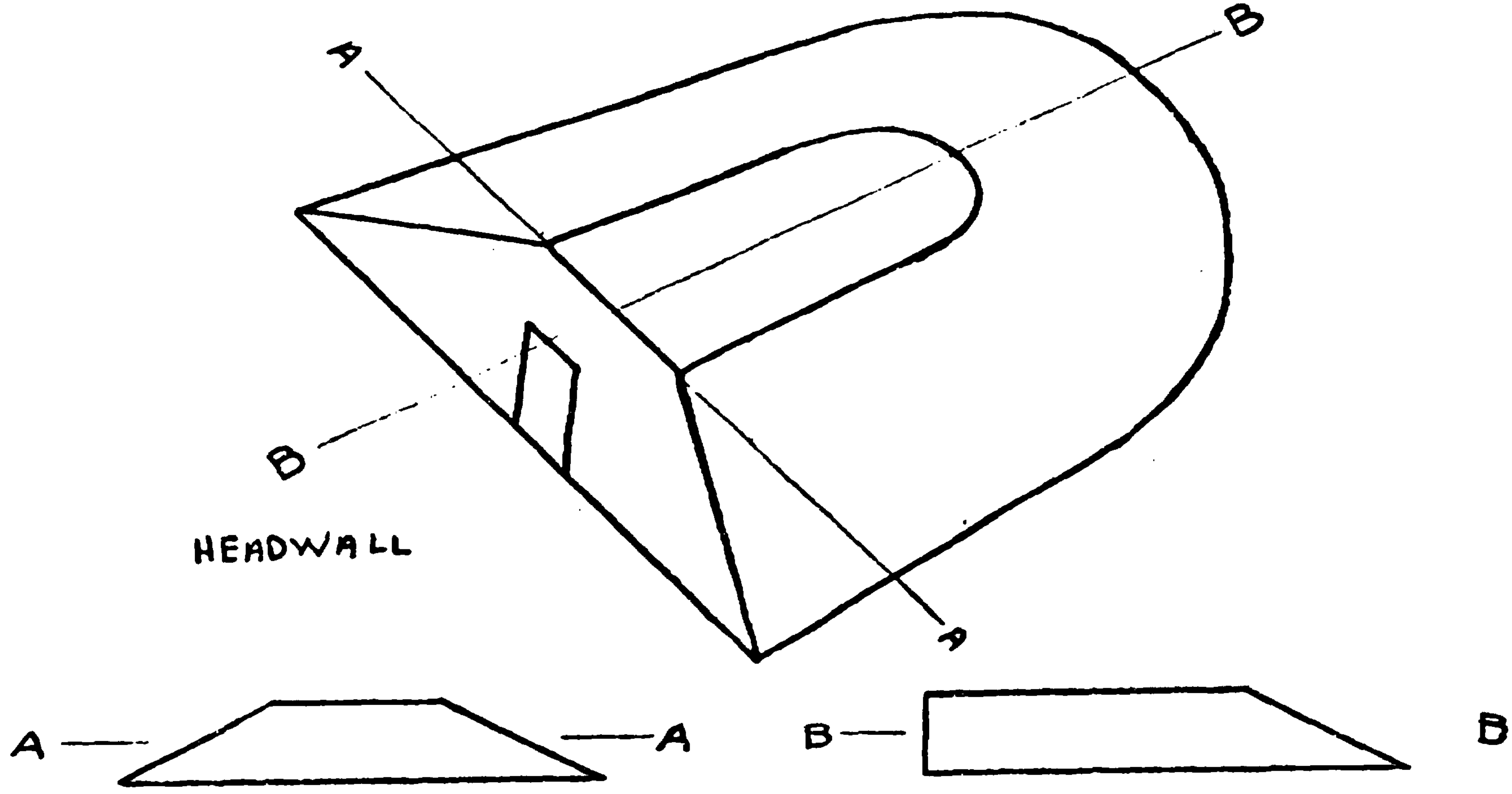


FIGURE 1 PRESENT DESIGN CONCEPT

been the most difficult to harden because when the doors are strengthened a greater load is placed on the headwalls and they tend to fail.

II. PROPOSED DESIGN CONCEPT

The design concept proposed in this report is based on the major areas of interest stated in the objectives. They are, reduce the blast and fragment; production from a donor and loading on an acceptor.

A. Extension of Earth Cover

The first approach in reducing both the blast and fragment production and loading is to extend the earth cover around the front of the structure. This approach is shown in Figure 2. There are two advantages gained from this modification. First the production of blast and fragments in the area in-line with the front of the igloo will be greatly reduced since blast and fragment pattern should be similar to that extending from the rear of the igloo.

The second advantage of this modification is in the reduction of external blast and fragment loading on the front of the structure. The blast loading would not be a normal reflection but at an angle of incidence of approximately 63° which would reduce the reflected pressure by more than 50 percent. The earth cover around the front would also stop the fragments with the exception of a small projected area slightly larger than the size of the door.

B. Tunnel Entranceway

The ideal approach in modifying existing igloos or designing new ones would be to use a tunnel entranceway which would have a 1:2 slope as shown in Figure 3. There are design problems with this concept because the large area to be covered by this first door would make it excessively heavy. Therefore it is proposed that the tunnel entranceway be extended as shown in Figure 4 and a vertical door be considered. The total pressure and impulse on the vertical door at the end of the tunnel will be much less than the loading on the present door because the relief of the reflected pressure will be much faster due to the short travel time of the rarefaction wave. Therefore the reflected impulse would also be less.

C. Door Design

There are two philosophies that can be explored in the design of doors for munition storage magazines. The first and present philosophy is to design the doors to withstand the blast and fragment loading by making them heavier and stronger. This puts added loading on the headwall or tunnel entrance.

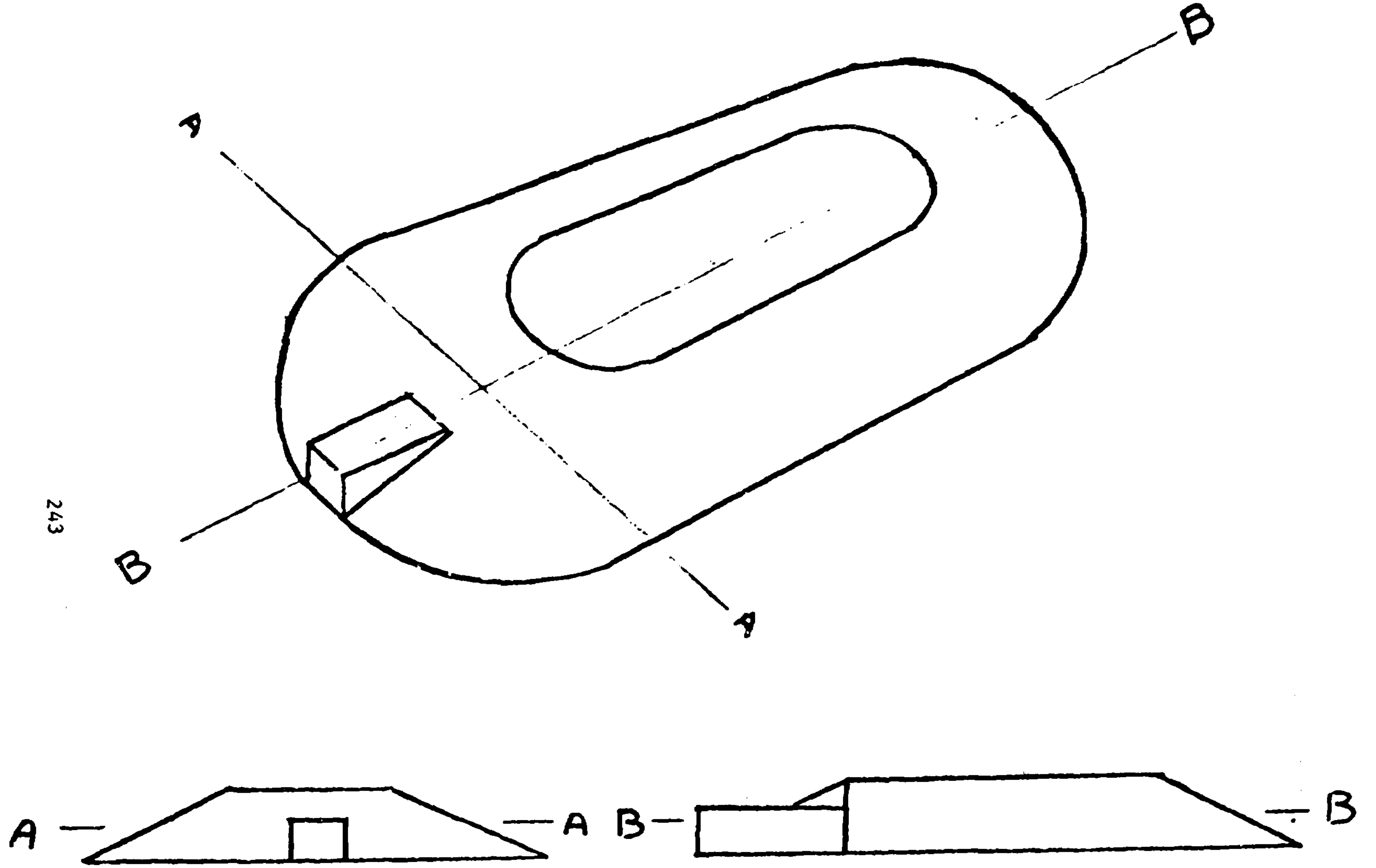


FIGURE 2. PROPOSED DESIGN CONCEPT

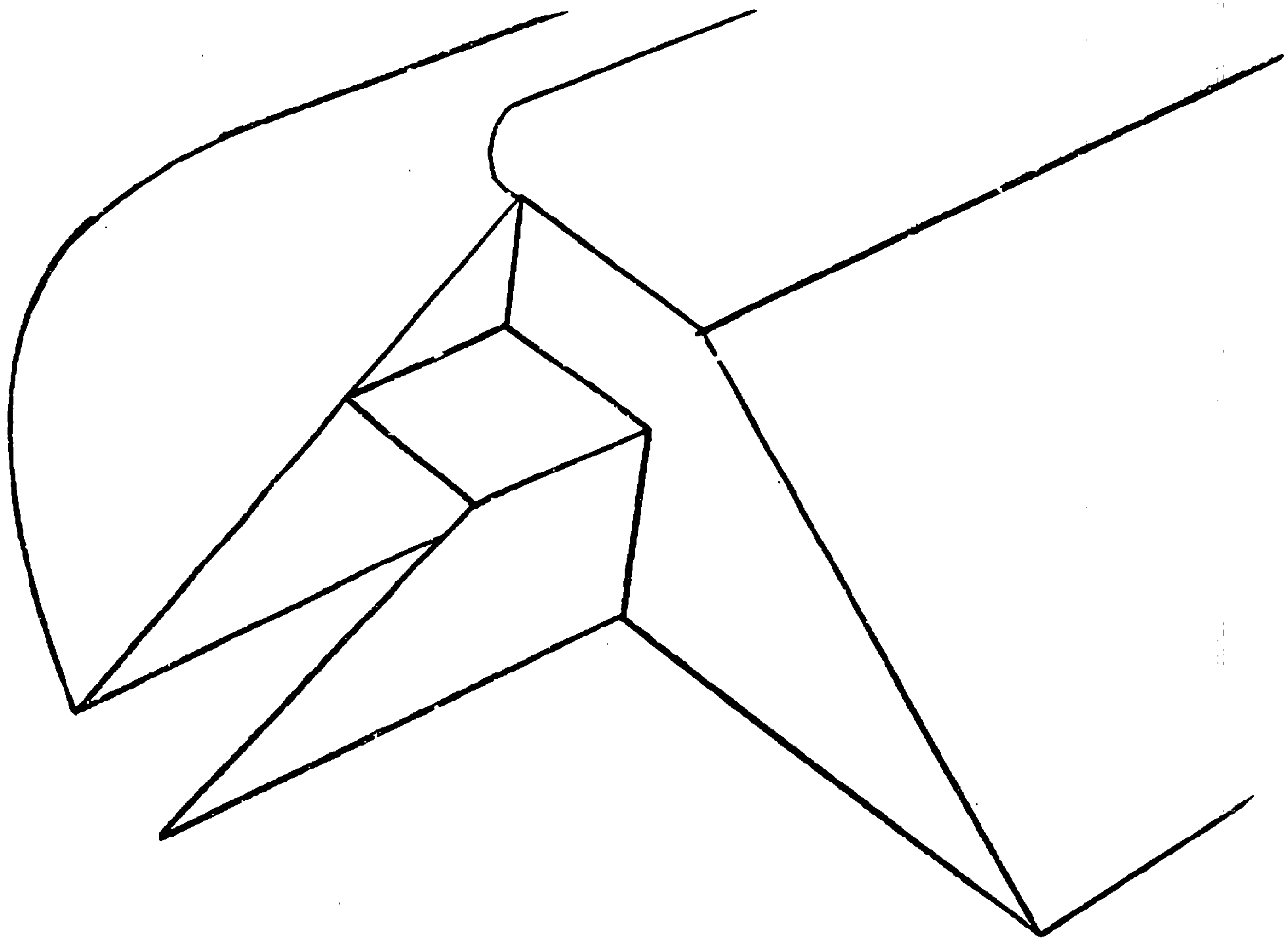


FIGURE 3. DETAIL OF SLOPED ENTRANCEWAY

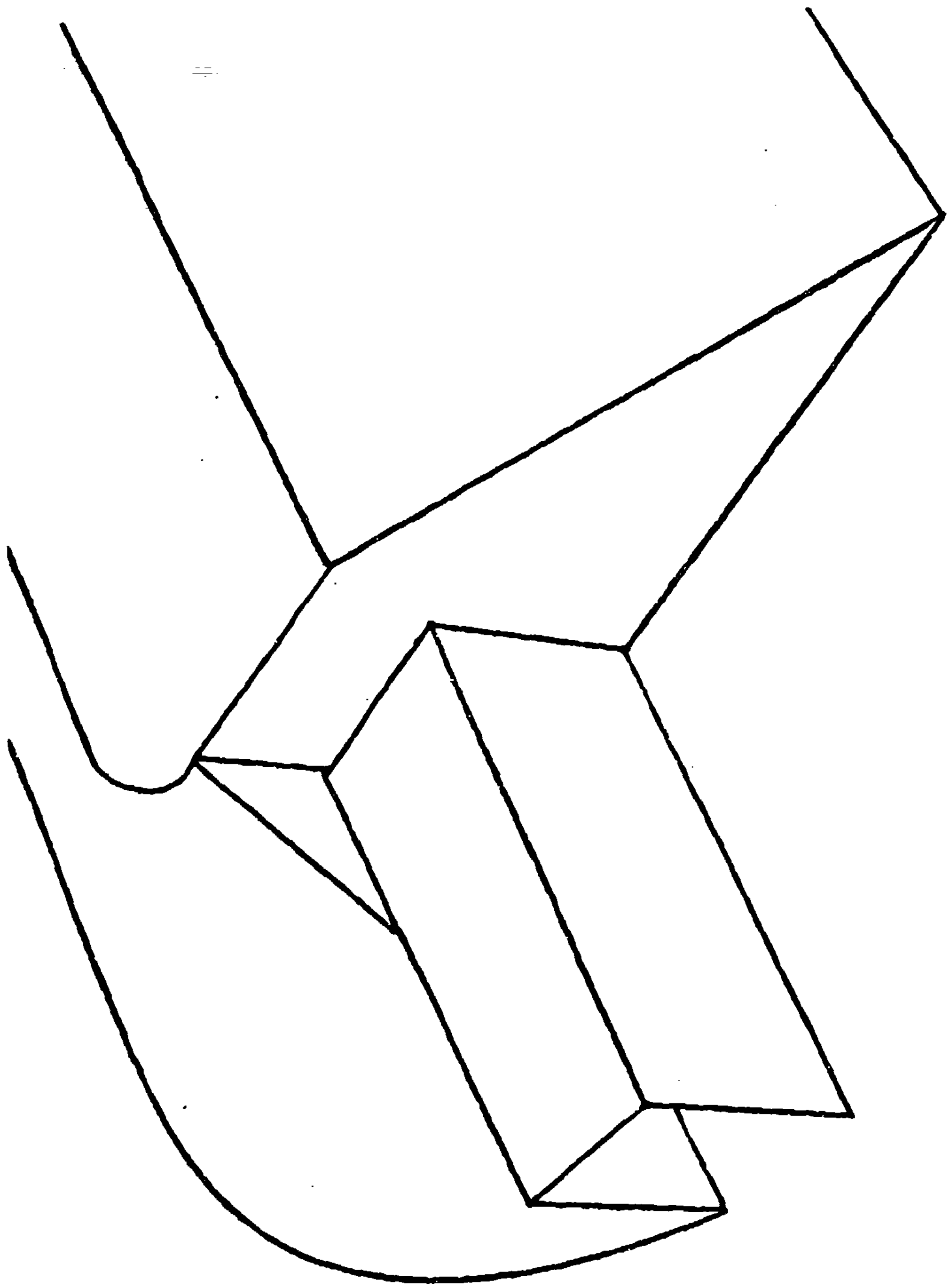


FIGURE 4 DETAIL OF VERTICAL ENTRANCEWAY

The second philosophy presented here as a suggested method for decreasing the loading on the headwall and entrance tunnel is an application of the suppressive structure technique. This technique was developed for use in de-mil work where there is a requirement to contain the fragments and blast within a given volume without constructing large reinforced concrete cubicles. It has been demonstrated that airblast from small charges can be attenuated as much as 90 percent by passing through a suppressive panel. A sketch of a proposed door is shown in Figure 5. The door consists of a layer of angle irons, a series of perforated plates and another layer of angle irons. With this type of door it would stop all fragments and debris but allow some of the airblast to pass through. This would mean a smaller reflected blast and impulse loading on the door and therefore it should remain in position for external loads. With the suggested tunnel entranceway it would be advantageous to install two doors; one at the tunnel entrance and one where the present headwall is located.

D. Application to Present Magazines

The concept as described in the preceding sections could be applied with relatively little expense to present storage magazines. It would require the addition of an entranceway tunnel, as shown in Figure 6, to the present headwall. These tunnels could be prefabricated for easy installation. The fins along the side are designed to take the load from the first door away from the headwall when it is covered with earth. The present doors could remain in place or be replaced by the suppressive blast type door.

III. CONCLUSIONS

The advantages of the proposed design concept will be restated in the following paragraphs.

A. Advantages of Earth Cover Extension

The extension of the earth cover has the following advantages:

1. Attenuates the production of fragments in the direction of the headwall from internal explosions.

2. Attenuates the fragment loading on the door and headwall from an external explosion.

B. Advantages of Tunnel Entranceway

The tunnel entranceway has the following advantages:

1. If applied to present magazines it allows the present doors and headwalls to remain intact.

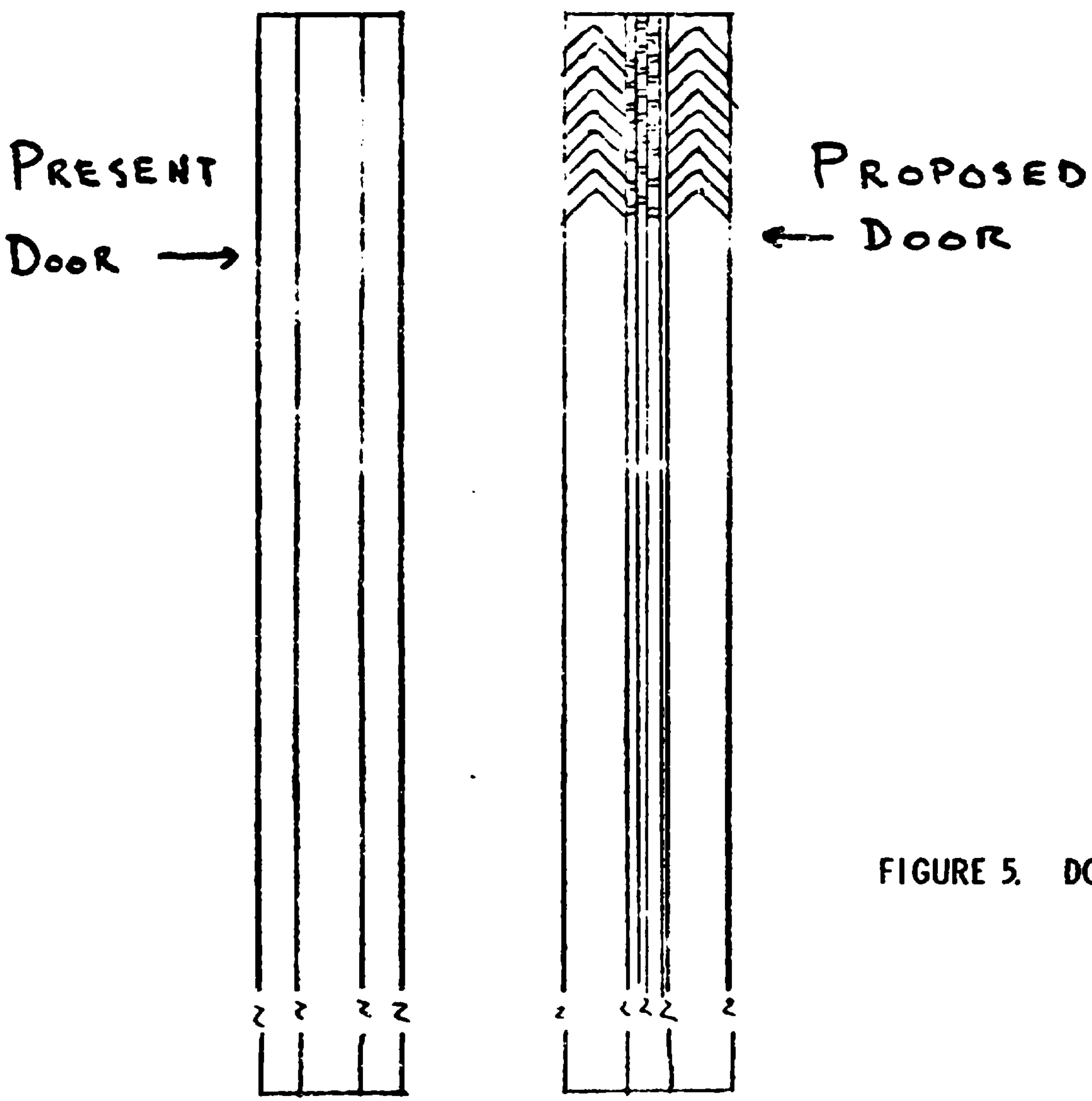


FIGURE 5. DOOR DESIGN

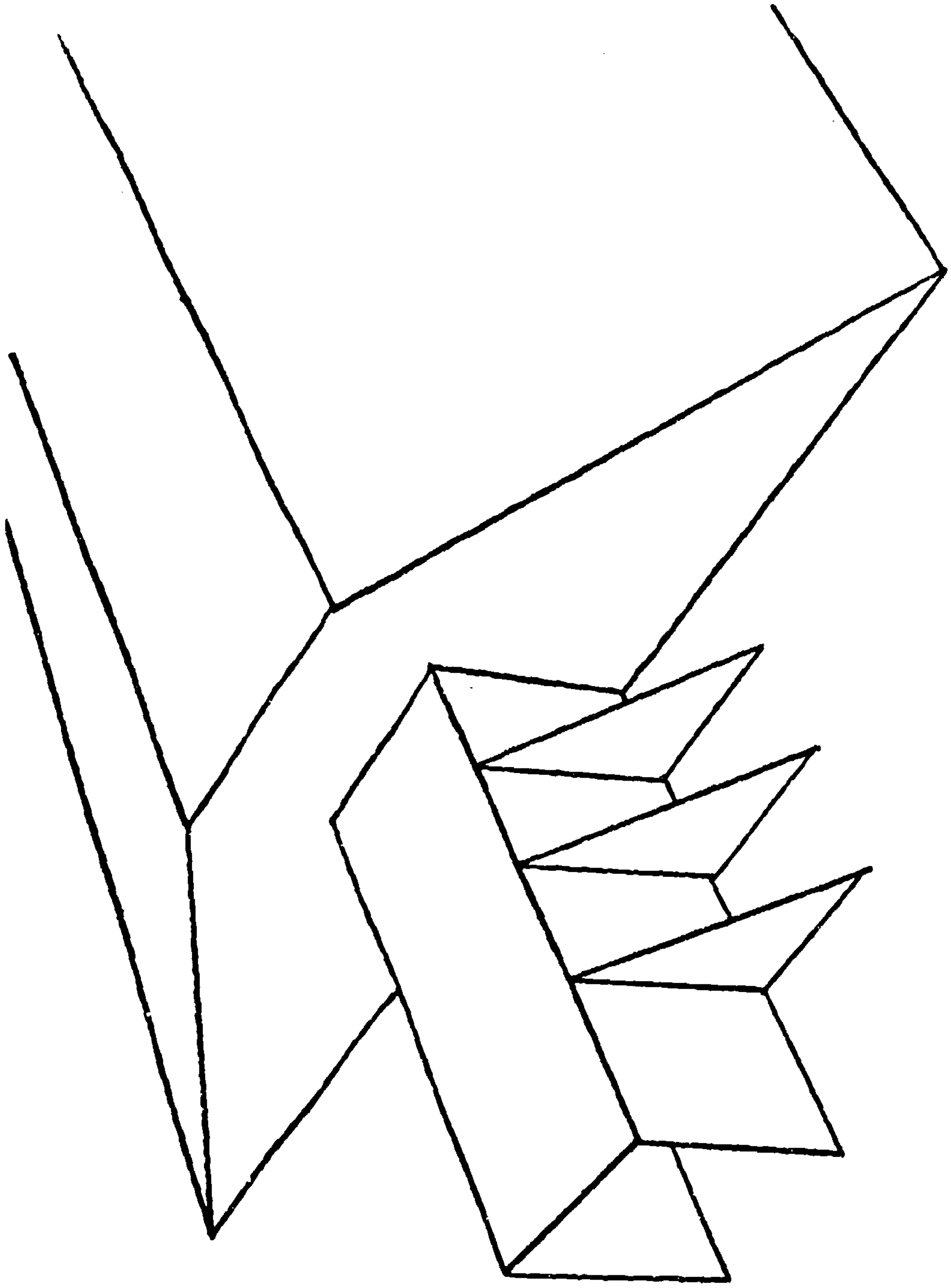


FIGURE 6 ENTRANCEWAY ADDITION DESIGN

2. It allows the use of two doors and relieves the loading on the first door from being transmitted to the headwall.

3. The tunnel entranceway also serves as a fragment trap for fragments other than those directly in line with the tunnel.

4. The tunnel entranceway and the two door concept will give added protection against sabotage.

C. Advantages of the New Door Design

The advantages of the application of the suppressive structure concept to magazine doors are listed as follows:

1. The new design door can be much lighter weight than the present doors.

2. The relief of the reflected pressure and the passage of blast through the door puts less loading on the door frame and headwall.

AIRBLAST EFFECTS ON WINDOWS IN BUILDINGS AND AUTOMOBILES ON THE ESKIMO II EVENT

E. R. Fletcher, D. R. Richmond, and R. K. Jones
Lovelace Foundation for Medical Education and Research
Albuquerque, New Mexico 87108

INTRODUCTION

Objectives

The objectives of this project were:

1. to determine the velocities, masses, and spatial densities of the fragments from three types of standard plate-glass windows mounted in closed, cubical structures at three ranges on the Eskimo II test;
2. to study the response of a clothed anthropomorphic dummy (a) standing behind one of the plate-glass windows and (b) sitting in an automobile; and
3. to estimate the hazards to occupants of buildings and automobiles exposed to similar levels of airblast.

Background

There are many civilian and military organizations concerned with the safety of personnel in the advent of a nearby accidental or intentional detonation of explosive materials. One major problem area has been the evaluation of the flying-glass hazard to occupants of buildings, houses, and automobiles. Experimental and theoretical studies have produced a fair amount of information regarding the conditions under which ordinary

windows will break, but considerably less is known about the characteristics of the resultant fragments. Reference 1 summarizes the available pertinent data which were obtained mostly by trapping glass fragments in sheets of Styrofoam (expanded polystyrene) placed behind windows in houses located in the vicinity of nuclear and HE detonations at overpressure levels between 1.0 and 5.0 psi. Most of these data were for windows with a glass thickness of from 0.082 to 0.13 inches, whereas the plate glass commonly used in buildings has a thickness of from 0.18 to 0.28 inches. The only data in Reference 1 for plate glass were obtained from five identical windows in one house exposed at an overpressure level of 2.7 psi. Thus, the Eskimo II test provided an opportunity to fill the gap by exposing plate-glass windows of several designs to lower overpressure levels than those that had been previously tested.

PROCEDURE

Modules

Ten 9-foot cubical boxes called modules were fabricated and positioned along the northwest radial (see Figure 1) by China Lake personnel. Three modules abutted one another at the 3400-foot range, three at 1700 feet, and four at 1210 feet. The only openings into each module were a hole where a window was mounted and an access door which was closed during the blast. All of the windows faced ground zero. Figure 2 shows a preshot view of the modules at the 1700-foot range.

Windows

The three types of windows tested are shown at the bottom of Table I. Types W1 and W2, designated as projected and horizontal-sliding,

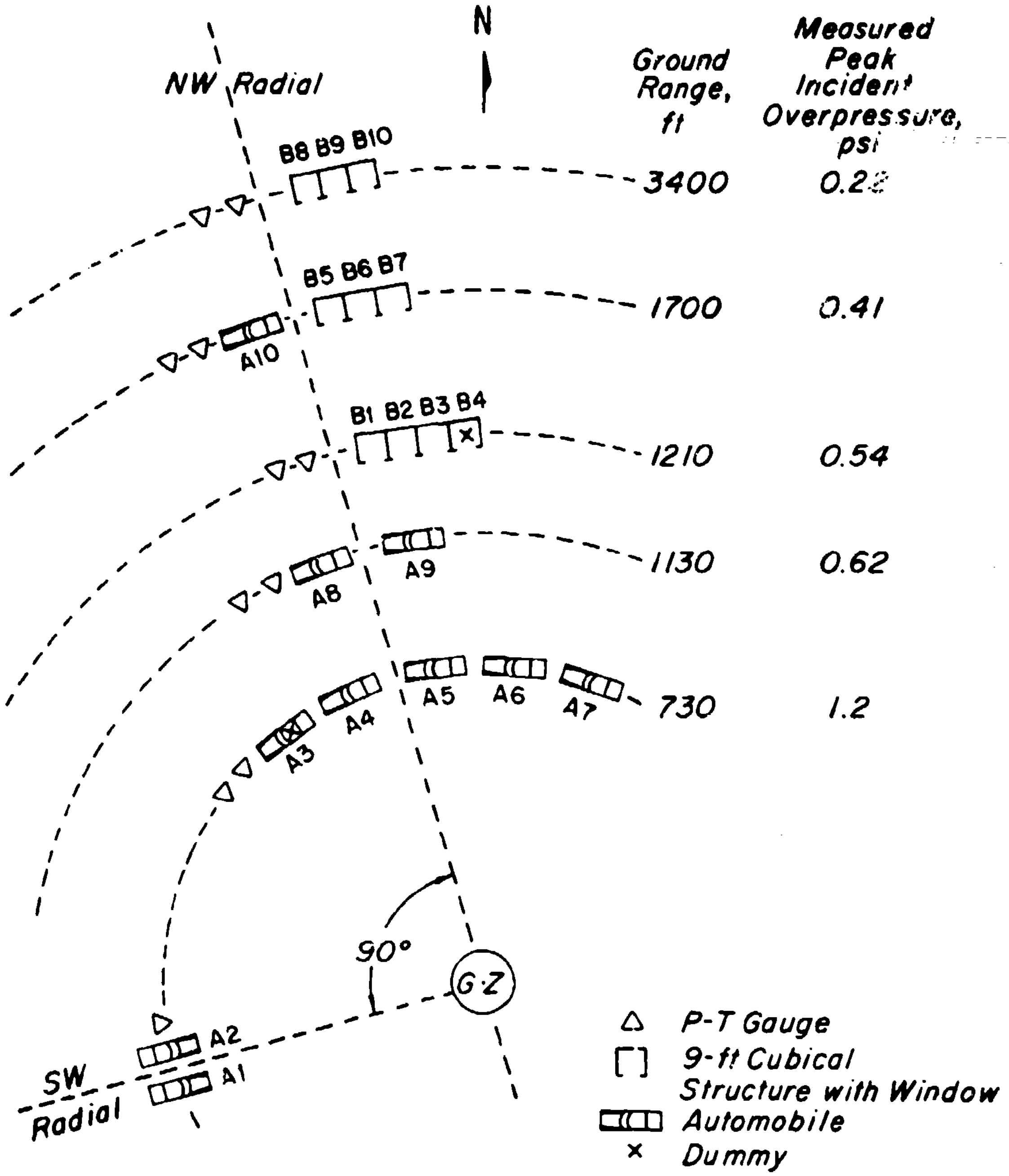


Figure 1. Field Layout for Eskimo II Test.

Figure 2. Preshot View of (from left to right) Modules B5, B6, and B7.

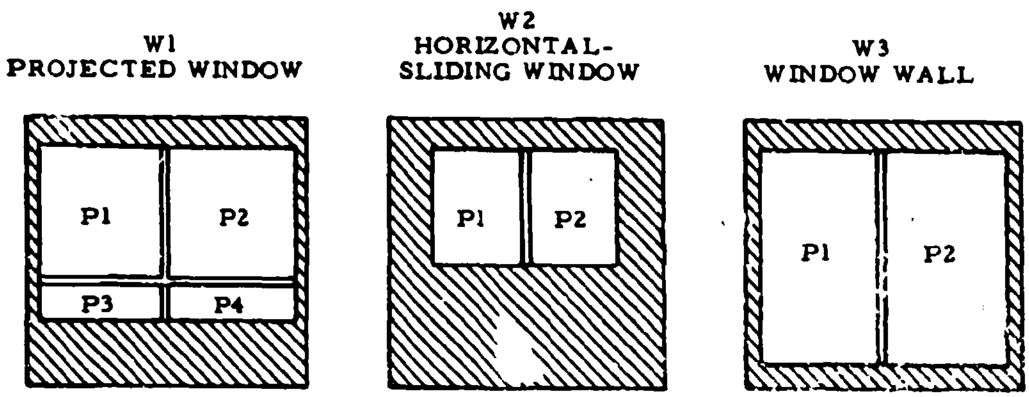
TABLE I

DESCRIPTION OF THE WINDOWS IN THE MODULES

Window Type	Parameters for Individual Panes					
	Number	Color*	Width, in.	Height, in.	Type of Glass	Frame Type
W1	P1	Copper	45	45	Plate	Fixed
	P2	Green	45	45	Plate	Fixed
	P3	Silver	42	20	Sheet	Top Opening
	P4	Black	42	20	Sheet	Top Opening
W2	P1	Copper	34	48	Sheet	Horizontal Sliding
	P2	Green	34	48	Plate	Fixed
W3	P1	Copper	48	90	Plate	Fixed
	P2	Green	48	90	Plate	Fixed

* A thin coat of paint was sprayed on both sides of each pane at 1210 and 1700 ft ground range but not at the 3400 ft ground range.

FRONT VIEWS OF THREE MODULES INDICATING WINDOW TYPE AND PANE NUMBERS



respectively, are commercial-type windows used extensively in government buildings and comply with, but do not exceed, the Architectural Aluminum Manufacturers Association (AAMA) specifications. The Type W3, window-walls, were mounted in a neoprene structural gasket system used in Federal office buildings but no AAMA specifications are available. Three Type W1, four Type W2, and three Type W3 windows were mounted one each in the ten modules. One window of each type was tested at each of the three ranges. The additional Type W2 window was located at the 1210-foot range. Some of the panes were spray painted different colors to aid in identifying the sources of the trapped fragments (see Table I).

Styrofoam

A Styrofoam witness plate was mounted on the inside back wall of each of six of the modules at the 1700- and 1210-foot ranges in an attempt to trap glass fragments if the window was broken by the blast wave. The witness plates were fabricated at the Lovelace Foundation using low-density Styrofoam (Type II, described in Reference 2) glued to 1/2-inch plywood. Each witness plate included two pieces of Styrofoam each 90 inches high, 32.5 inches wide, and 6 inches thick. Prior to fabrication, calibration techniques described in Reference 2 were used to develop a formula for determining the velocity of a fragment from its mass and the volume of the impression it made in the Styrofoam. In each module the distance from the window to the surface of the Styrofoam was approximately 84 inches.

Cloth Sheets

A cloth sheet (95 inches wide, 95 inches high) was hung behind the window in each of the three modules at the 3400-foot range in order to estimate possible penetration of clothing if the windows broke. The four sides of the sheets were fastened to wooden frames positioned 47 inches behind the windows.

Automobiles

Ten conventional automobiles were utilized on this test (see Figure 1); eight were situated left-side-on on the northwest radial (one at 1700 feet, two at 1130 feet, and five at 730 feet), and two were exposed face-on on the southwest radial (730 feet). No Styrofoam was placed in any of the automobiles.

Dummies

Two anthropomorphic dummies attired in summer civilian clothing were supplied by the Lovelace Foundation for this test. One of the dummies was standing 35 inches behind pane P2 in the B4 module at 1210 feet. This module did not contain any Styrofoam witness plates. The dummy faced the window with his chest resting lightly against a narrow metal rod intended to stabilize his position prior to shock arrival while not interfering with subsequent possible blast displacement. The other dummy was secured by means of a lap seat belt in the driver's seat of a left-side-on station wagon located at 730 feet on the northwest radial (see Figure 1).

Cameras

Two high-speed (400 frames per second) motion-picture cameras were used by China Lake personnel to record the responses of the two dummies. A reference grid was painted on the portion of the module wall in the field of view of the camera in order to facilitate velocity determinations for the glass fragments and the dummy.

Overpressure Gauges

Eleven self-recording BRL mechanical gauges were positioned, two each, at the 3400-, 1700-, 1210-, 1130-, and 730-foot ranges on the northwest radial and one at the 730-foot range on the southwest radial. These were supplied by China Lake.

RESULTS AND DISCUSSION

General

All of the modules remained structurally intact and none of the cloth sheets or Styrofoam witness plates were damaged or displaced by the blast experience. A total of 426 fragments were trapped from 14 of the 17 panes which broke. Window damage was noted in eight of the ten automobiles on the layout. Dummy and glass responses were satisfactorily documented with both motion-picture cameras. Good pressure-time records were obtained from all gauges and average measured peak incident overpressures are given in Figure 1 for the five ranges of interest.

Windows in Modules

The 26 panes of glass exposed in the modules are listed in Table II along with such information as glass thickness, whether or not the

TABLE II

FRAGMENT FOR THE WINDOWS IN THE MODULES

Ground Range, ft	P_i, psi	P_r, psi	t_+, msec	Module Number	Window Type	Pane Number	Glass Thickness, in.	Number of Trapped Fragments	V_{50}, ft/sec	M_{50}, gm	A_{50}, in.^{2}	E_{gm} or E_{ga}	b	E_p	E_{gv}	ρ_d, frags. per ft^2	ρ_w, frags. per ft^2
1210	0.54	1.10	158	B1	W2	P1 P2	0.219 0.227	42 10	66.6 35.9	4.14 9.07	0.467 0.967	3.54 7.38	-0.215 -0.237	0.0451 0.0565	1.39 1.40	3.10 0.866	2.05
				B2	W3	P1 P2	0.226 0.225	22 58	35.6 59.9	25.6 6.52	2.80 0.716	4.10 4.07	-0.188 -0.231	0.0764 0.0431	1.62 1.57	1.27 3.61	2.50
				B3	W1	P1 P2 P3 P4	0.231 0.224 0.121 0.120	19 25 59 84	52.9 51.4 66.6 72.0	12.2 8.09 2.51 1.19	1.30 0.892 0.512 0.245	4.73 3.38 3.57 3.66	-0.229 -0.275 -0.211 -0.113	0.0490 0.0709 0.0316 0.0304	1.38 1.51 1.36 1.42	1.99 2.55 6.09 7.20	6.54
				B4	W2	P1 P2	0.219 0.226	** **	- 52†	- -	- -	- -	- -	- -	- -	- -	-
				Data from B1, B2, and B3 combined			0.120 0.224	143 176	69.2 52.1	1.64 8.09	0.337 0.892	3.77 4.48	-0.155 -0.244	0.0220 0.0217	1.62 1.54	6.92 2.33	
1700	0.41	0.83	180	B5	W3	P1 P2	0.227 0.226	1 15	11.0 40.0	15.0 9.37	1.63 1.02	- 3.62	- -0.345	- 0.125	- 1.83	0.111 1.55	0.831
				B6	W1	P1 P2 P3 P4	0.232 0.225 0.120 0.120	0 11 46 26	- 37.8 58.4 72.9	- 4.78 1.82 0.655	- 0.525 0.374 0.135	- 8.35 3.67 3.34	- -0.139 -0.238 -0.284	- 0.0452 0.0473 0.0602	- 1.35 1.51 1.44	0 0.997 5.10 2.88	4.49
				B7	W2	P1* P2	0.219 0.227	0 3	- 50.4	- 9.82	- 1.07	- -	- -	- -	- -	0 0.332	0.166
				Data from B5, B6, and B7 combined			0.120 0.226	72 30	63.3 38.4	1.26 [illegible]	0.259 0.816	3.86 5.05	-0.268 -0.237	0.0343 0.0664	1.48 1.78	3.99 0.598	
3400	0.22	0.44	202	B8	W3	P1* P2*	0.232 0.227	** **	- -	- -	- -	- -	- -	- -	- -	0 0	0
				B9	W1	P1* P2* P3* P4*	0.232 0.227 0.119 0.123	** ** ** **	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	0 0 0 0	0
				B10	W2	P1* P2*	0.219 0.227	** **	- -	- -	- -	- -	- -	- -	- -	0 0	0
Total Number of Trapped Fragments								421‡									

* This pane did not break.
** There was no Styrofoam in the module containing this pane.
† Velocity estimated from the motion-picture record (397 frames per second).
‡ Overall, an additional 5 fragments were trapped for which M and V were not calculated (see text) bringing total number of fragments trapped to 426.

pane broke, and the number of fragments trapped. All ten panes at 1210 feet seven of the eight panes at 1700 feet, and none of the eight panes at 3400 feet broke. As expected, only a portion of the glass from the broken panes was actually trapped. This is indicated by the number of fragments on the floor below the Styrofoam shown in Figure 3, a postshot view through the frame of pane P1 in module B2. Table II also contains the average measured peak incident overpressure, P_i, the calculated (using P_i) peak overpressure in the reflected wave at the front of the modules, P_r, and the average measured duration of the positive phase of the incident overpressure, t_p.

The masses and velocities were determined by procedures described in Reference 2 for all but five fragments which struck so close to other fragments that the measured volumes of the impressions in the Styrofoam were suspect. As in the past, it was noted that for each pane an approximately linear relationship existed between the logarithms of the velocities and the logarithms of the masses of the fragments. A least-squares linear-regression analysis was performed for each pane and the results appear in Table II where V_{50} and M_{50} are the geometric mean fragment velocity and mass, respectively; b and E_b are the slope and the standard error in the slope of the regression line, respectively; and E_{gv} is the geometric standard error of estimate of fragment velocity. In addition, A_{50} is the geometric mean frontal area of the fragments (calculated from the density and thickness of the glass and M_{50}), and E_{gm} and E_{ga} are the geometric standard deviation of the fragment masses and frontal areas, respectively. All 426 fragments were used

Figure 3. Postshot View Through the Frame of P1 Showing the Styrofoam Witness Plate in B2.

in computing the densities of trapped fragments which, for each pane, tended to be constant over an area of Styrofoam equal to the size of the pane. This area was, in general, centered somewhat below the center of the pane as a result of the fragments' having fallen (due to gravity) in traversing the distance from the frame to the Styrofoam. Likewise, the density of trapped fragments for an entire window (i. e., counting the fragments from all of the panes) tended to be approximately constant over an area of Styrofoam equal in size to the window but displaced downward. The computed average densities (designated as ρ_d and ρ_w for the individual panes and entire windows, respectively) over these areas of approximately constant density are listed in Table II.

It was noted that the fragment data for panes of approximately the same thickness located at the same ground range tended to be very similar. Therefor the data were combined into four groups representing panes approximately 1/4- or 1/8-inch-thick located at the 1210- or 1700-foot ground range. These groups are shown in Figures 4 through 7. The results of a regression analysis for each of the four groups are given in Table II where it can be noted that for six panes of approximately 1/4-inch-thick glass at 1210 feet the mean velocity of trapped fragments was 52.1 ft/sec compared to 52 ft/sec for the pane which struck the dummy as estimated from the motion-picture record.

Figures 4 through 7 also contain the regression lines as well as lines drawn one standard error of estimate on either side of the regression lines. In addition, the figures contain curves indicating the

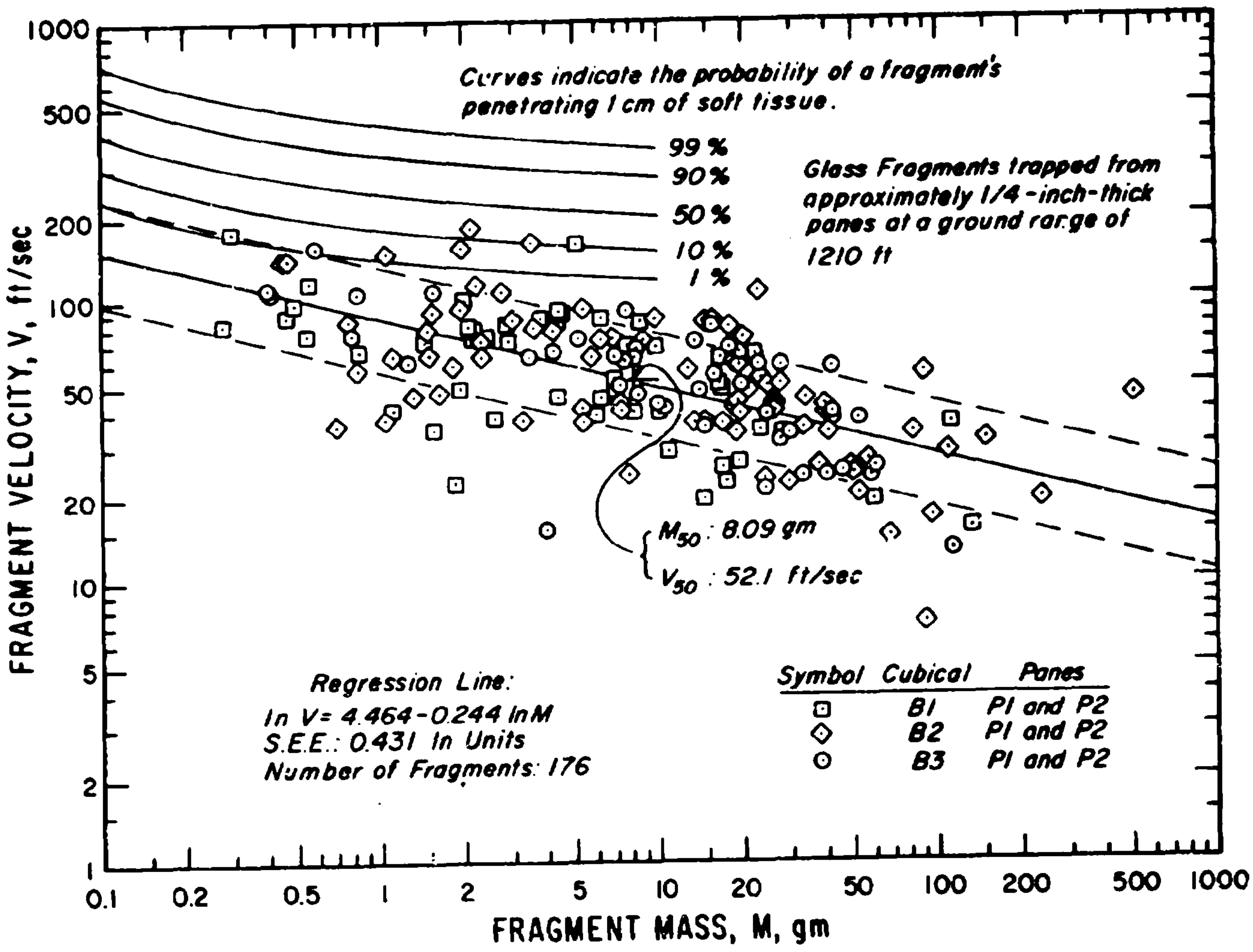


Figure 4. Glass Fragments Trapped from Approximately 1/4-Inch-Thick Panes at a Ground Range of 1210 Feet.

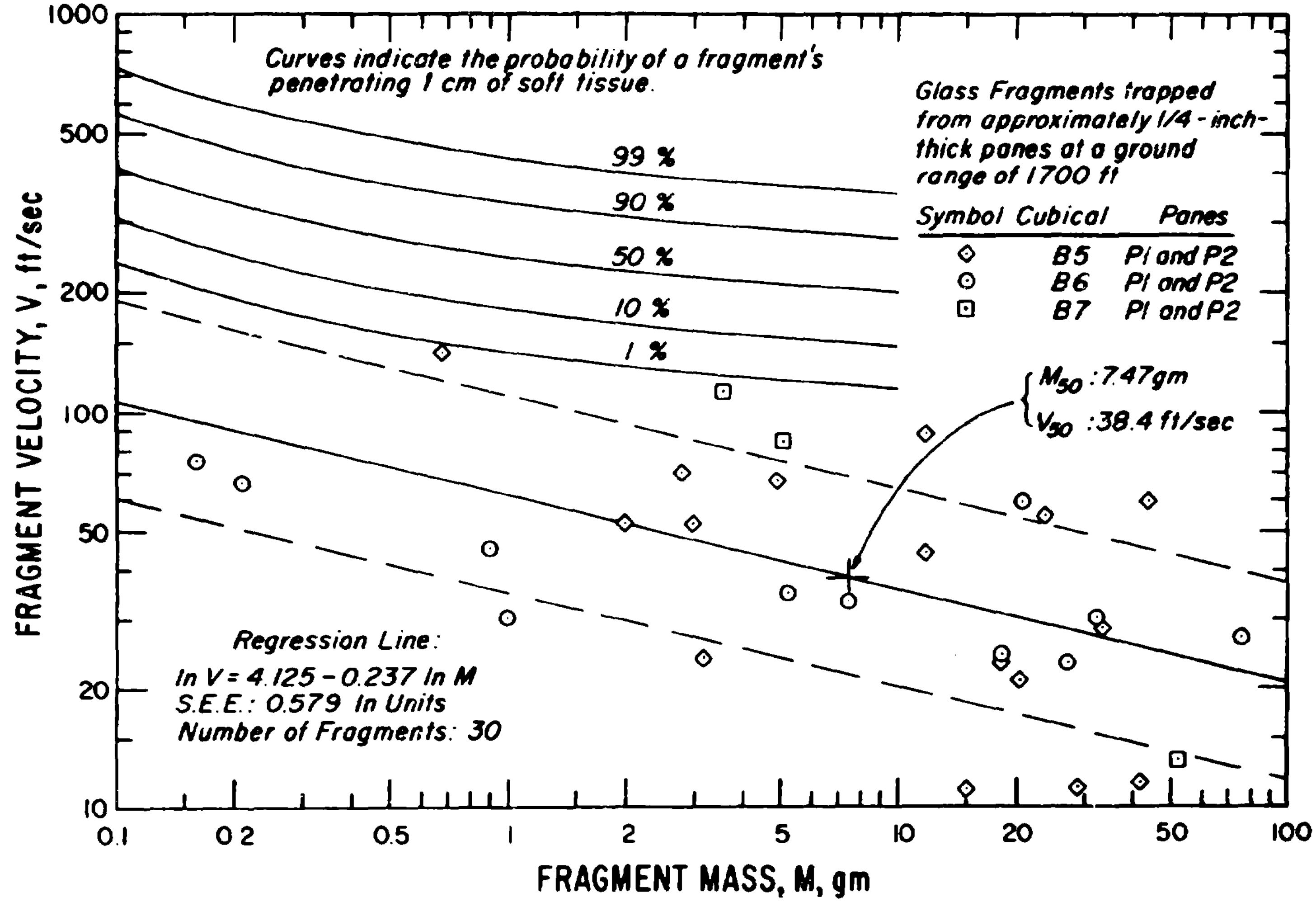


Figure 5. Glass Fragments Trapped from Approximately 1/4-Inch-Thick Panes at a Ground Range of 1700 Feet.

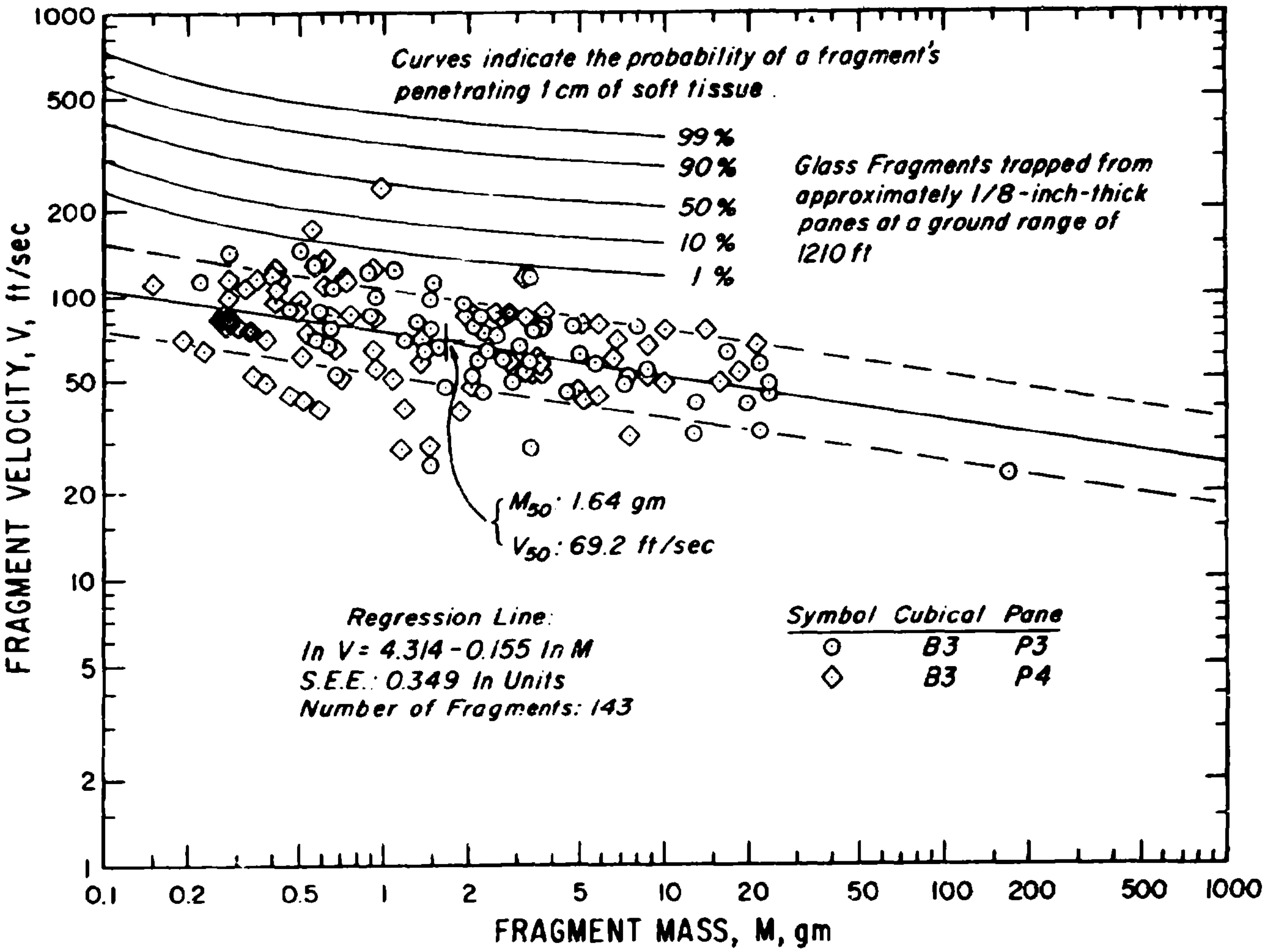


Figure 6. Glass Fragments Trapped from Approximately 1/8-Inch-Thick Panes at a Ground Range of 1210 Feet.

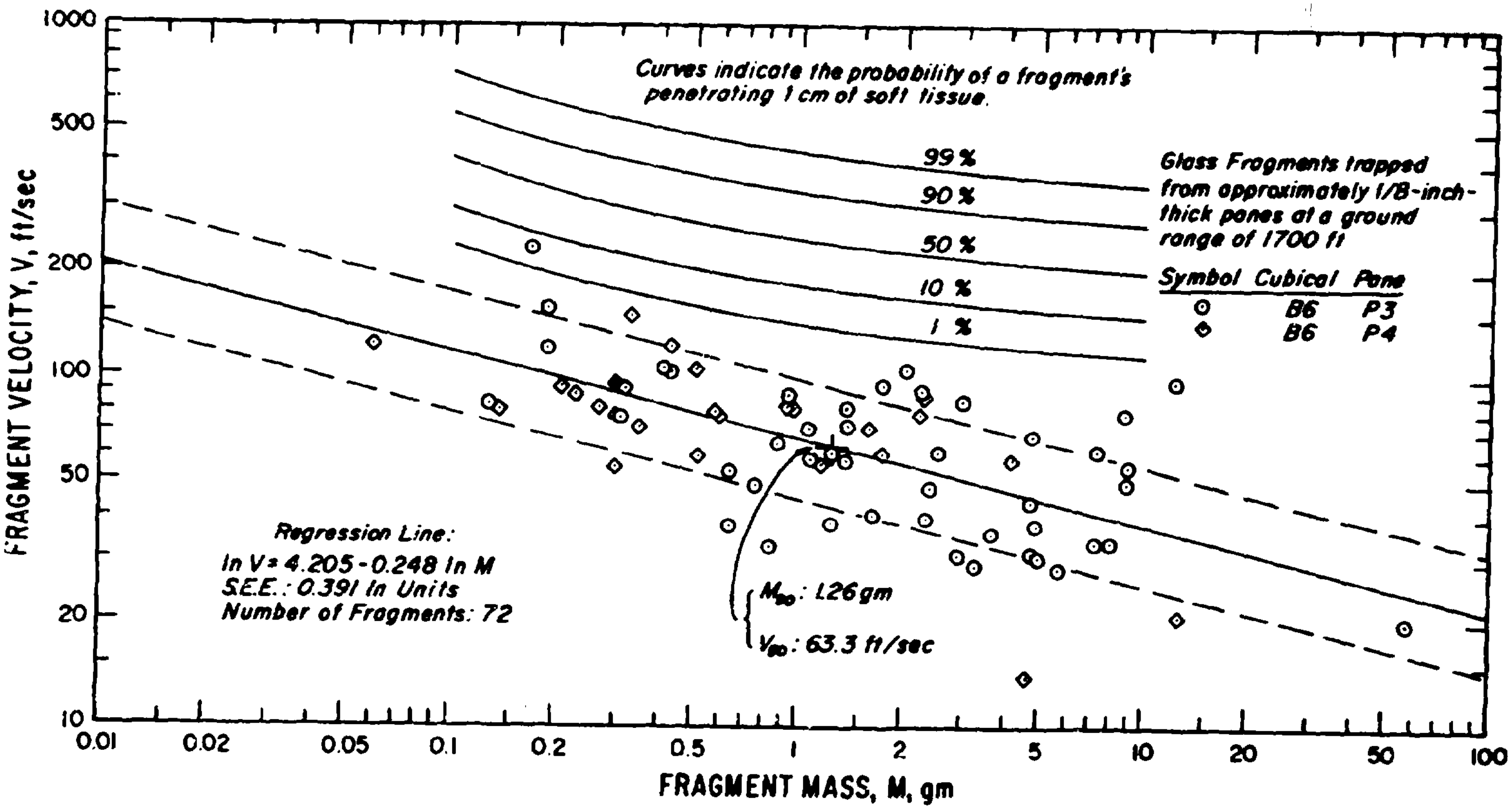


Figure 7. Glass Fragments Trapped from Approximately 1/8-Inch-Thick Panes at a Ground Range of 1700 Feet.

probability of a fragment's penetrating 1 cm of soft tissue as given in Reference 3. It can be seen that, of the 421 trapped fragments for which masses and velocities are available, only ten had at least a 1.0-percent probability of penetrating 1 cm of soft tissue. These fragments are listed in Table III. Nine of the ten occurred at the 730-foot range where fragments were trapped behind eight panes giving an average of about one fragment per pane with a significant ($\geq$1.0 percent) probability of penetrating 1 cm of soft tissue. The highest probability computed at this range was 44 percent. In contrast, only one fragment with a significant probability (4.0 percent) of penetrating was caught behind the eight panes at the 1700-foot range giving an average of about one-tenth fragment per pane.

In order to make comparisons between this and prior experiments, the current data were plotted in Figures 8 through 10 which were modified from Reference 1. In these figures, it can be seen that the fragment velocities, frontal areas, and densities for the current data tend to line up reasonably well with the corresponding values for the prior data when plotted against effective peak overpressure, taken to be P_r for the current data since all the windows faced the advancing blast wave. However, on all three figures the current data tend to fall above the regression curve based on the prior data only. Thus, the current data suggest that in each case the shape of the regression curve might need to be modified for the lower overpressures. In the case of the mean fragment velocity, this is probably because the fragments with low velocities will not be caught in the Styrofoam.

TABLE III

WINDOW GLASS FRAGMENTS WITH A SIGNIFICANT* PROBABILITY OF PENETRATING 1 CM OF SOFT TISSUE

Module Number	Pane Number	Fragment Mass, gm	Fragment Velocity, ft/sec	Probability of Penetrating 1 cm of Soft Tissue, percent
B1	P1	0.29	178	1.4
		5.03	160	12.0
B2	P2	1.03	149	1.6
		1.95	154	4.0
		3.51	162	11.0
		2.11	187	21.0
B3	P2	0.58	154	1.1
	P4	0.55	169	2.3
		0.97	239	44.0
B6	P3	0.17	233	4.0

* ≥1.0 percent.

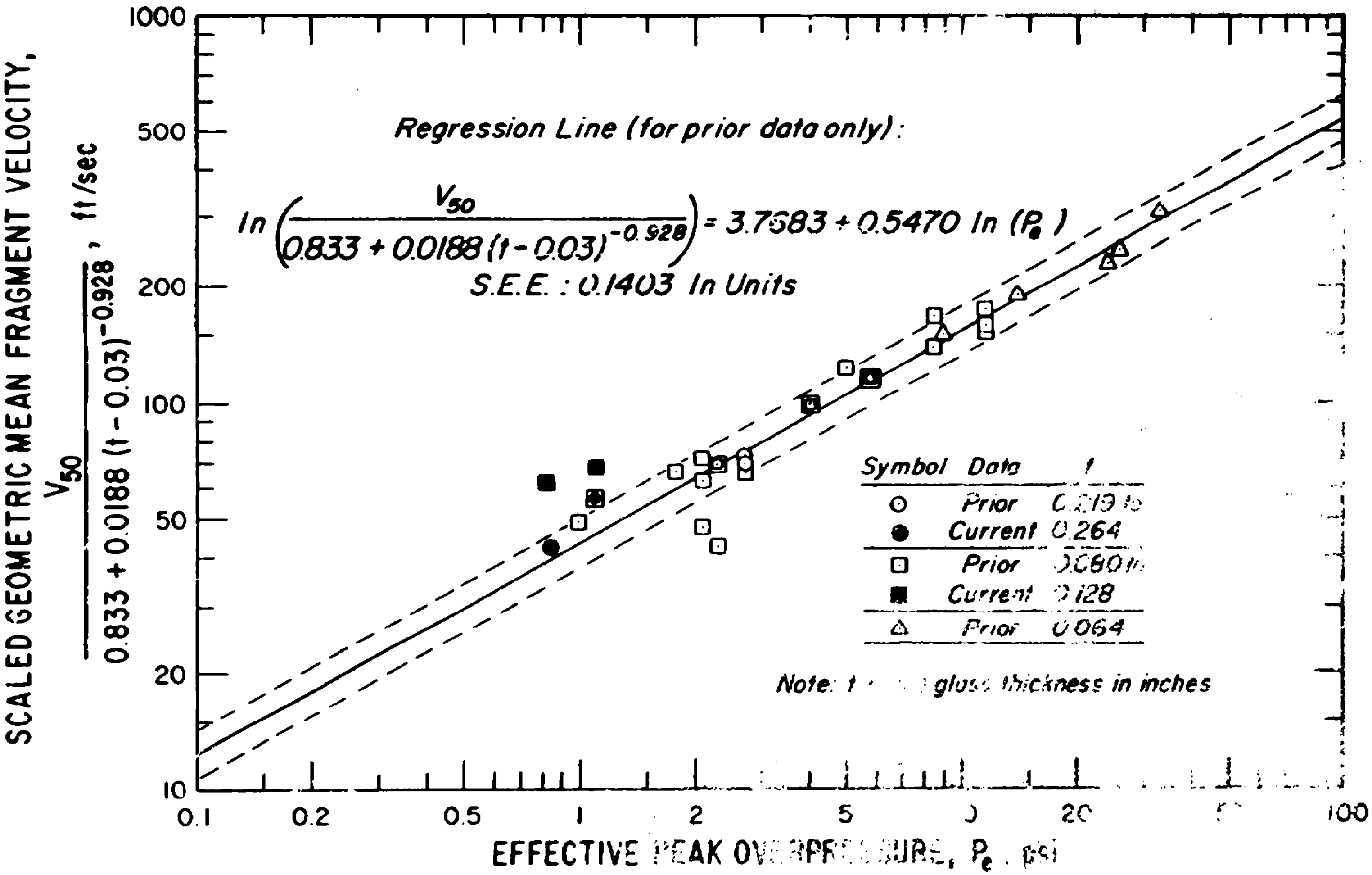


Figure 8. Scaled Geometric-Mea[illegible] Fr[illegible]gr[illegible]nt Velo[illegible] vs. Effective Peak Overpressu[illegible].

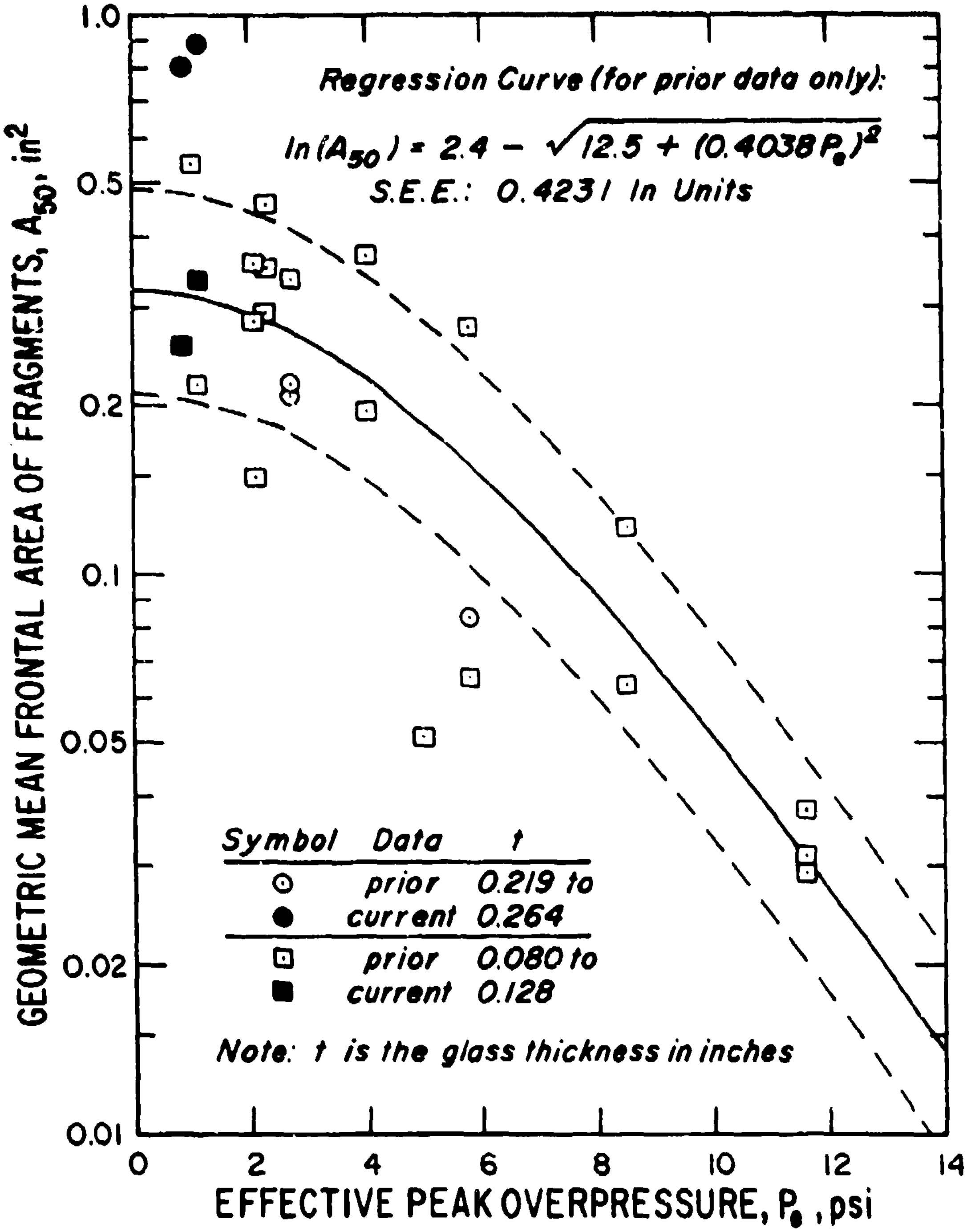


Figure 9. Geometric-Mean Frontal Area of Fragments vs. Effective Peak Overpressure.

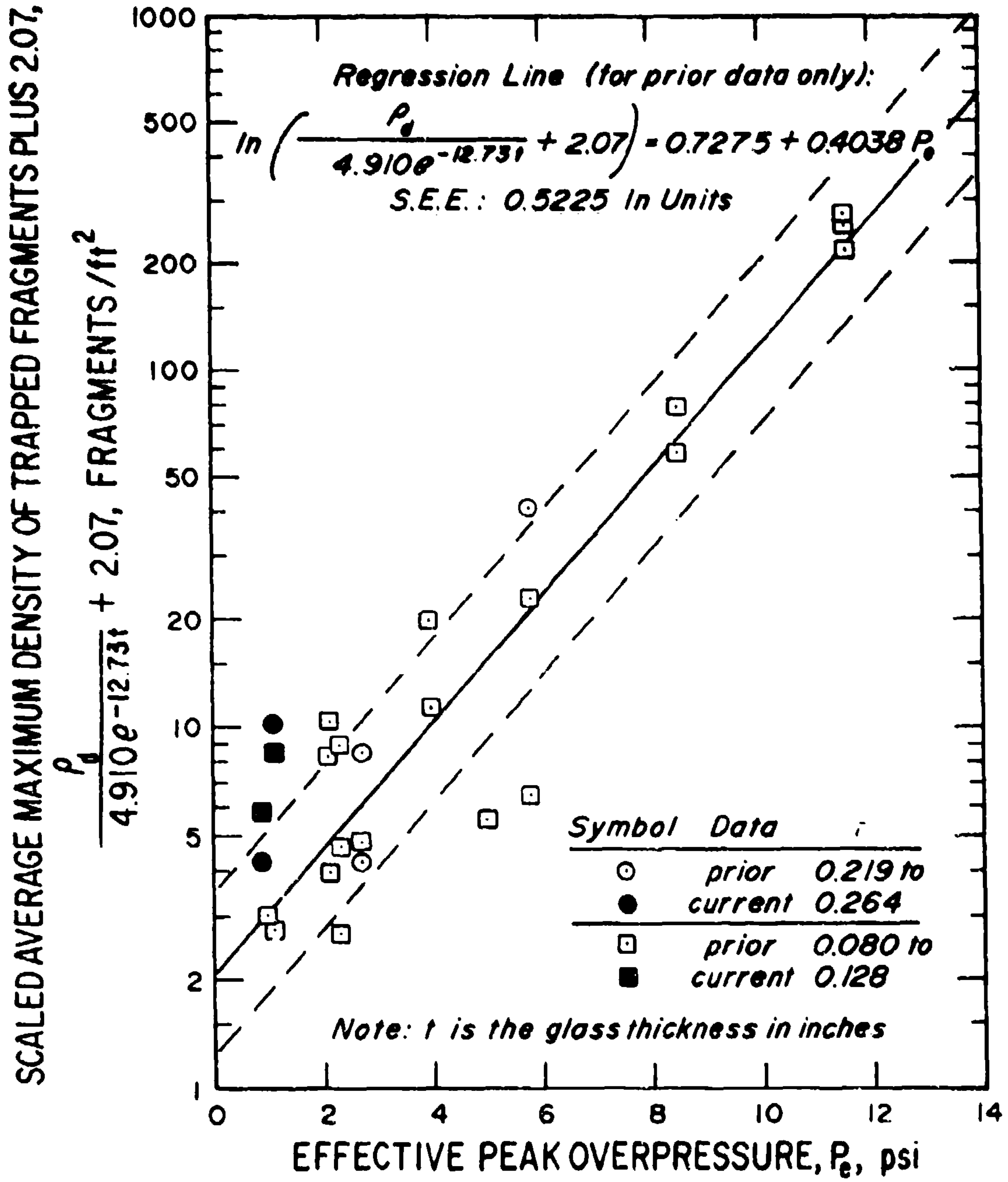


Figure 10. Scaled Average Max.mum Density of Trapped Fragments Plus 2.07 vs. Effective Peak Overpressure.

Dummy in Module

The window pane (P2) 35 inches in front of the dummy was broken by the blast wave. From the motion-picture record it was determined that many fragments struck the upper half of the dummy with an average velocity of about 52 ft/sec. However, the only effects noted on the dummy were three 1/8-inch-diameter holes in the shirt. One was located near the left shoulder and two were along the left arm about the level of the elbow. There was no damage or lacerations to the dummy itself beneath the small holes in the shirt and the fragments did not adhere to the material.

As a result of being struck by the blast wave and glass, the dummy was accelerated such that his head and center of mass were moving backward at 1.2 and 0.75 ft/sec. respectively. He was found in a supine position and, although the actual impact could not be seen in the film record, it was estimated that his head and center of mass impacted the floor at vertical velocities of 20 and 13 ft/sec, respectively. It was further estimated that the dummy required about 1.3 sec to impact the floor which is about twice the predicted average time required for the glass fragments to fall to the floor. It would thus be expected that the dummy would fall on top of the glass fragments on the floor, and such was found to be the case. Several large cuts were found on the back of the hat and shirt of the dummy as a result of his having fallen onto the glass.

Windows in Automobiles

The locations of the automobiles on the layout are indicated in Figure 1, and the observed window damage is documented in Table IV.

TABLE IV

AUTOMOBILE WINDOW DAMAGE

Ground Range, ft	P_1, psi	Automobile			Windows Damaged	Extent of Window Damage
		Orientation	Number	Description		
730	1.2	Face-On	A1	Renault	None	None
			A2	Pontiac	Windshield Left Rear-Door Right Front-Door Right Rear-Door	Completely broken out Multiple fractures Completely broken out Multiple fractures
		Left Side-On	A3	Dodge* Station Wagon	Windshield Left Rear-Door (Side)**	Multiple fractures Completely broken out
			A4	VW	Left Door	Completely broken out
			A5	Peugeot	Left Front-Door Right Front-Door	Completely broken out Completely broken out
			A6	Chevrolet	Windshield Left Rear-Door	Multiple fractures Completely broken out
			A7	Dodge Fuel Truck	Left Door Left Vent	Multiple fractures Multiple fractures
1130	0.62	Left Side-On	A8	VW Bus	Windshield	Multiple fractures
			A9	Lincoln	Windshield	Multiple fractures
1700	0.41	Left Side-On	A10	Buick	None	None

* An anthropomorphic dummy was secured in the driver's seat of this station wagon by means of a lap seat belt.

** Analysis of the film record from the camera (402 frames per second) viewing this window indicated that the fragments had a mean velocity of about 11 ft/sec.

Note: There was no evidence that any of the automobile windows were broken by bomb fragments or crater ejecta rather than by the airblast itself.

At 730 feet (1.2 psi) the most common damage was to windshields and door windows, particularly on the side of the automobile facing the oncoming blast wave. On the average, about two windows per automobile were damaged, of which approximately one half completely broke out and one half sustained multiple fractures but remained in place. Both automobiles at 1130 feet (0.62 psi) sustained only multiple fractures of the windshields. None of the windows in the automobile at 1700 feet (0.41 psi) were damaged. There was no evidence that any of the automobile windows were broken by bomb fragments or crater ejecta rather than by the airblast itself.

Fragments from the window which broke out in automobile A3 traveled across the field of view of the motion-picture camera. From analyzing this record, it was determined that their average velocity was about 11 ft/sec. It is estimated that fragments with this low of a velocity would have a very small probability of penetrating 1 cm of soft tissue.

Dummy in Automobile

No damage was observed to the dummy secured by means of a lap seat belt in the driver's seat of the left-side-on station wagon (A3) at 730 feet (1.2 psi). The only window which broke out in this automobile was the one in the left rear side door, but none of the fragments struck the dummy. From the motion-picture record it was determined that the dummy suffered no significant displacement during the blast experience.

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MECHANISMS IN SHOCK INITIATION OF DETONATION

Philip M. Howe
Terminal Ballistics Laboratory W, Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland 21005

At the BRL, we have been very much concerned with being able to generate criteria by which one could predict the sensitivity of high explosives to various shock loading conditions, and as a function of the physical properties of the explosive.

Qualitatively, and in a rather gross sense, the mechanisms of initiation of detonation are well understood. Early investigations of the shock initiation of physically homogeneous explosive systems; such as nitromethane, have shown the initiation mechanism to be consistent with the assumption of shock heating with subsequent chemical reaction (ref. 1,2). After an induction time, enough heat is released, due to chemical reaction, to cause a detonation to occur at the rear surface of the charge and propagate through the shocked medium, eventually overtaking the initial shock wave. However, when the explosive charge is physically inhomogeneous, such that there are density discontinuities within the explosive, the initiation does not result only from bulk heating, but rather depends strongly upon ignition occurring at sites where the shock waves interact with these inhomogeneities. These two modes of initiation are shown schematically in Figure 1.

As shown in Figure 1, the heterogeneous mode of initiation tends to produce a smooth acceleration of the shock wave to a steady detonation state. The homogeneous mode is characterized by a discontinuity in the initial shock velocity at the point in time and space where the detonation wave overtakes it These two modes represent extremes in behavior. There is evidence in the literature showing that both modes can be present in the same system (references 3,4,5). The degree to which each mode contributes is determined by the physical state of the explosive.

The initiation of detonation in homogeneous systems has been modelled successfully by means of thermal explosion theory (ref. 2). However, this theory has been less successful in the treatment of heterogeneous initiation. The reason for this is because of the additional complications in the initiation introduced by the hotspots. The presence of density discontinuities introduces local perturbations in temperature when the sample of explosive is shock loaded, and the sensitivity of the explosive presumably can depend upon, (1) ignition of reaction at hotspots; and (2) establishment of a burning reaction within the bulk explosives. Thus, it becomes very important to understand how these two processes contribute to the initiation process and how their effects are influenced by the physical state of the explosive, i.e., by the explosive density, particle size, etc.

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Lindstrom studied the shock initiation of tetryl as a function of loading density (ref. 6). His results, shown in Figure 2, clearly indicate that more than one mechanism is operative with a change in dominant mechanism occurring between the 1.70 g/cc density and the 1.60 g/cc density systems. The interpretation given by Lindstrom was that the buildup processes were independent of density, depending only upon the particle velocity for weak shocks, and became primarily pressure dependent for strong shocks. Howe re-examined the data of Lindstrom and discovered that the data for the four lower densities had a common minimum value for the particle velocity, at which value the time to detonation approached infinity (ref. 7). This was interpreted as evidence for a minimum hotspot energy density for ignition. The further assumption was made that the buildup curve was controlled by a surface area (void volume fraction to the two-thirds power) dependent grain burning reaction. These assumptions allowed scaling of the data as shown in Figure 3.

A major weakness of the above interpretation was that it required assumption of the loading density - surface area relationship. Boyle et al overcame this difficulty by creating a heterogeneous explosive system using nitromethane with inclusions, where the inclusion volume percentage and size were carefully controlled (ref. 8). Their results, shown in Figure 4, support the grain burning assumption, as the time to detonation was clearly inversely proportional to the total surface area of the inclusion. Suprisingly, they were able to introduce a scaling factor which accounted for the effects of difference in shock impedence.

Scott examined the effect of particle size upon initiation of detonation (ref. 9). He concluded, after Seely (ref. 10), that the shock sensitivity problem consists of two steps, ignition and reaction, and "that larger particles are more sensitive than smaller particles" i.e., that ignition occurs more easily for large particle size samples, and that "smaller particles, once initiated, more readily reach a stable, high order detonation".

Marshall studied the effect of interstitial gas on the shock sensitivity of coarse, granular HMX (ref. 11). His results show that the sensitivity of the system, i.e., the minimum pressure required to initiate detonation, was markedly dependent upon the nature and initial pressure of the interstitial gas. However, a plot of lost time (proportional to time to detonation) versus attenuator thickness shows that the lost time is independent of the pressure and nature of the gas, and depends only on the pressure of the initiating shock. These results were interpreted by Marshall as indicating the presence of two mechanisms.

The first of these, an ignition mechanism, determined whether or not the charge will detonate, and was strongly affected by the nature and presence of the gas. The second mechanism operated during the buildup phase, accounted for nearly all of the lost time, and was independent of the gas properties and pressure.

In light of the above, it is instructive to reconsider the data of Boyle (ref. 8) et al. In Figure 5, his data are replotted, showing the time to detonation versus the total inclusion surface area per unit volume. All of these data were obtained using the same input shock pressure; the difference in slopes of the two inclusion materials. The results shown in Figure 5 are clearly consistent with the data of Scott, when it is realized that the smaller the particle size, the greater the surface area, therefore, the more rapid the buildup to detonation.

The importance of all of the above work is that it suggests that one must consider the initiation process as consisting of two consecutive processes; an ignition step, dependent strongly upon local perturbations in energy density, and a buildup phase, dependent strongly upon the surface area of the density discontinuities. To check this hypothesis, the data of Boyle et al were replotted, using a set of coordinates which might show this. Figure 6 shows the time to detonation, plotted on the ordinate, versus the reciprocal of the total inclusion surface area per unit volume. For each type of inclusion, a linear relationship is obtained, showing indeed that the process is governed by a surface area dependent rate process. However, the ordinate intercept is non-zero and different for the two types of inclusions, showing clearly that there is a contribution to the time to detonation that is not surface area dependent. We identify that time as being the induction time for ignition, dependent only upon the nature of the density discontinuity, the strength of the initial shock, and the chemistry of the explosive.

Boyle et al used an energy density factor to account for the relative efficiencies of the two types of inclusions. This factor was obtained by calculating the energy density in the explosive after it had been processed by the shock reflected from an inclusion. An empirical relation was then obtained by plotting the time to detonation versus this energy density for a single buildup curve, obtained with a system containing 10% (volume) 80 micron Al203 powder. The result of introducing this correction factor is shown in Figure 7. The important things to note are that (1) the slopes of the two curves are the same indicating that the energy density factor correctly accounts for the buildup behavior, and (2) a non-zero intercept of the ordinate persists. From this, one can conclude that the evolution of the buildup is proportional to a function of the hotspot energy density and is inversely proportional to the inclusion surface area. Furthermore, a measurable, but small contribution to the time to detonation arises from from a surface area independent ignition phase, which contribution depends upon the internal energy density.

In summary, experimental evidence to date suggests that the shock initiation of physically heterogeneous explosives is best considered in terms of two processes; an ignition process, independent of the surface area of the density discontinuities, and a buildup process strongly dependent upon the surface area.

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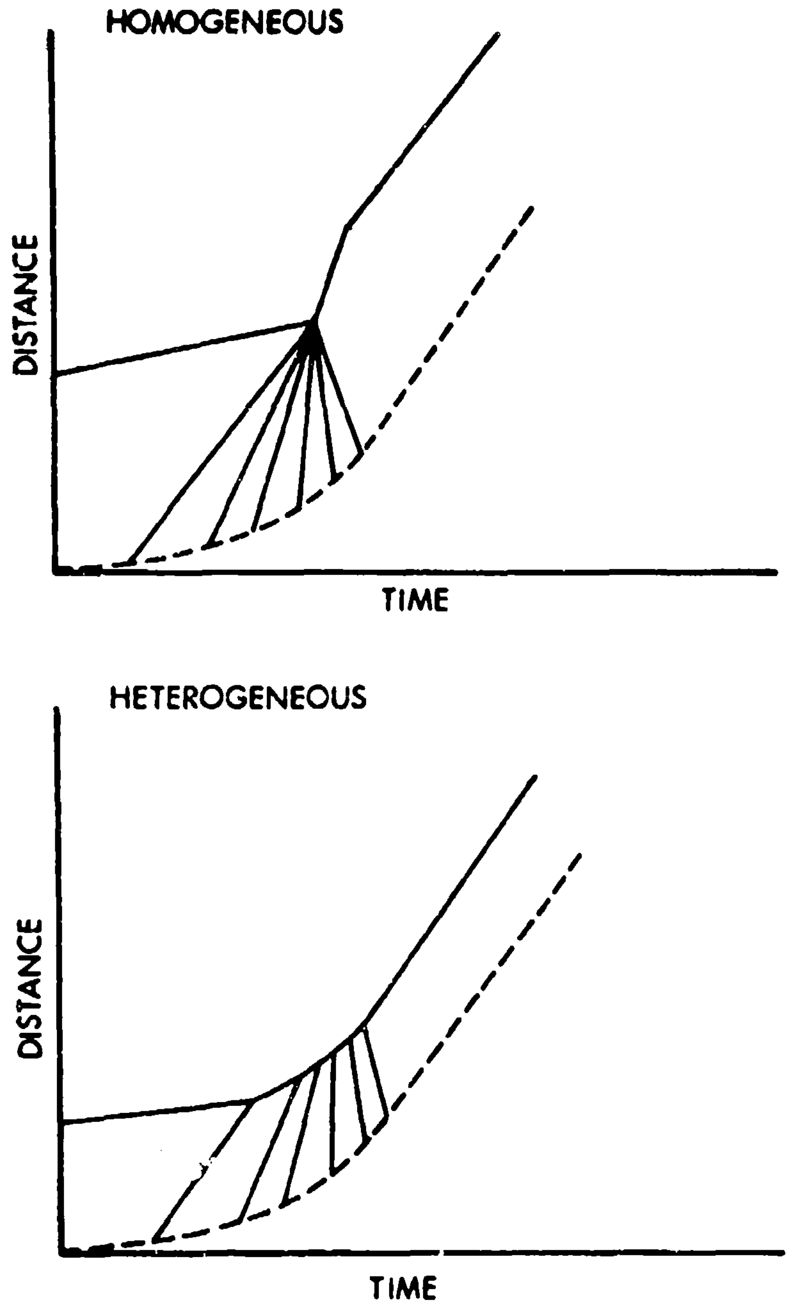

Figure 1. Schematic Diagram Showing Two Extremes of Initiation Behavior.

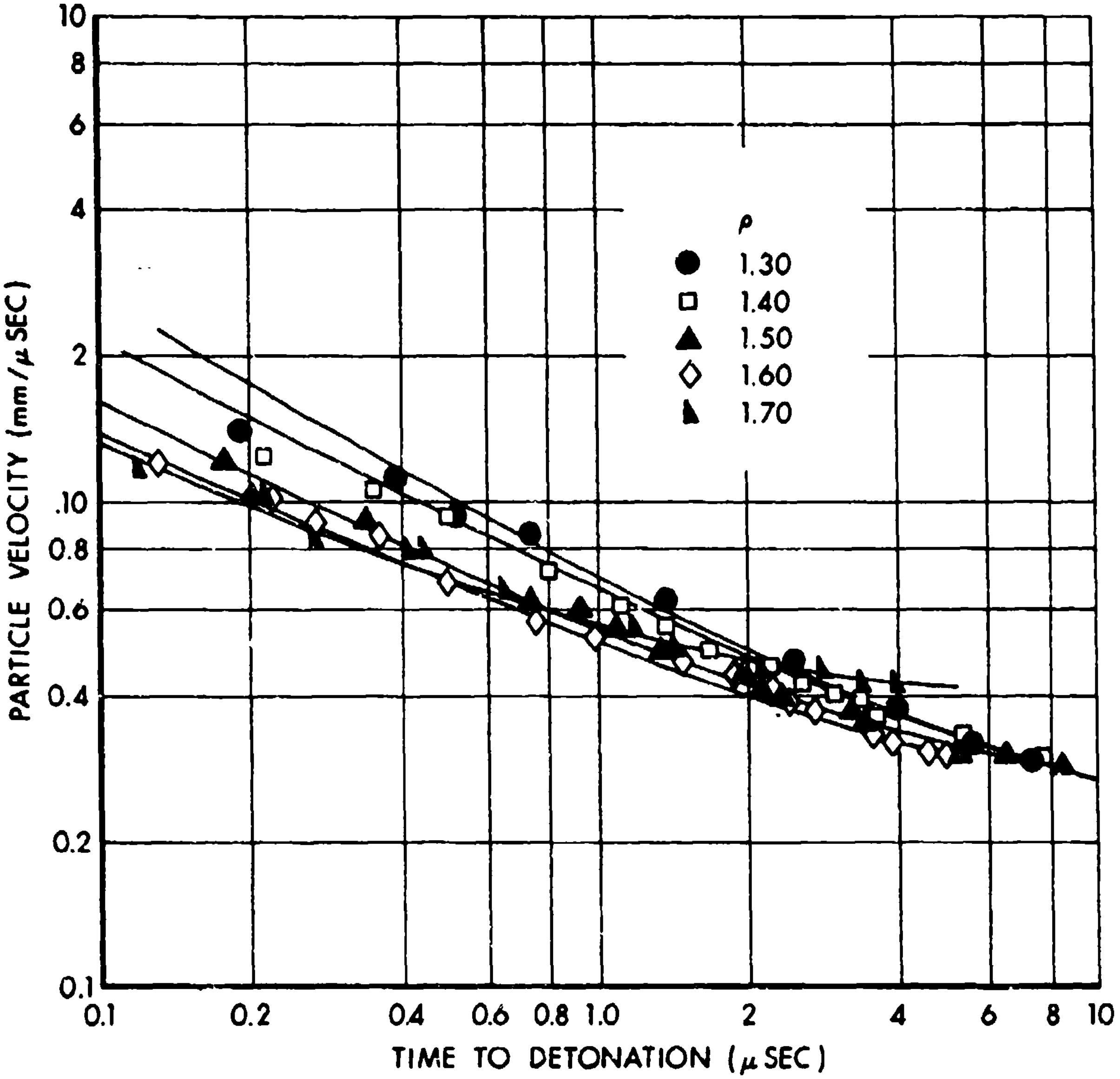

Figure 2. Buildup Data for Pressed Tetryl (Ref. 6) Showing Presence of Two Mechanisms.

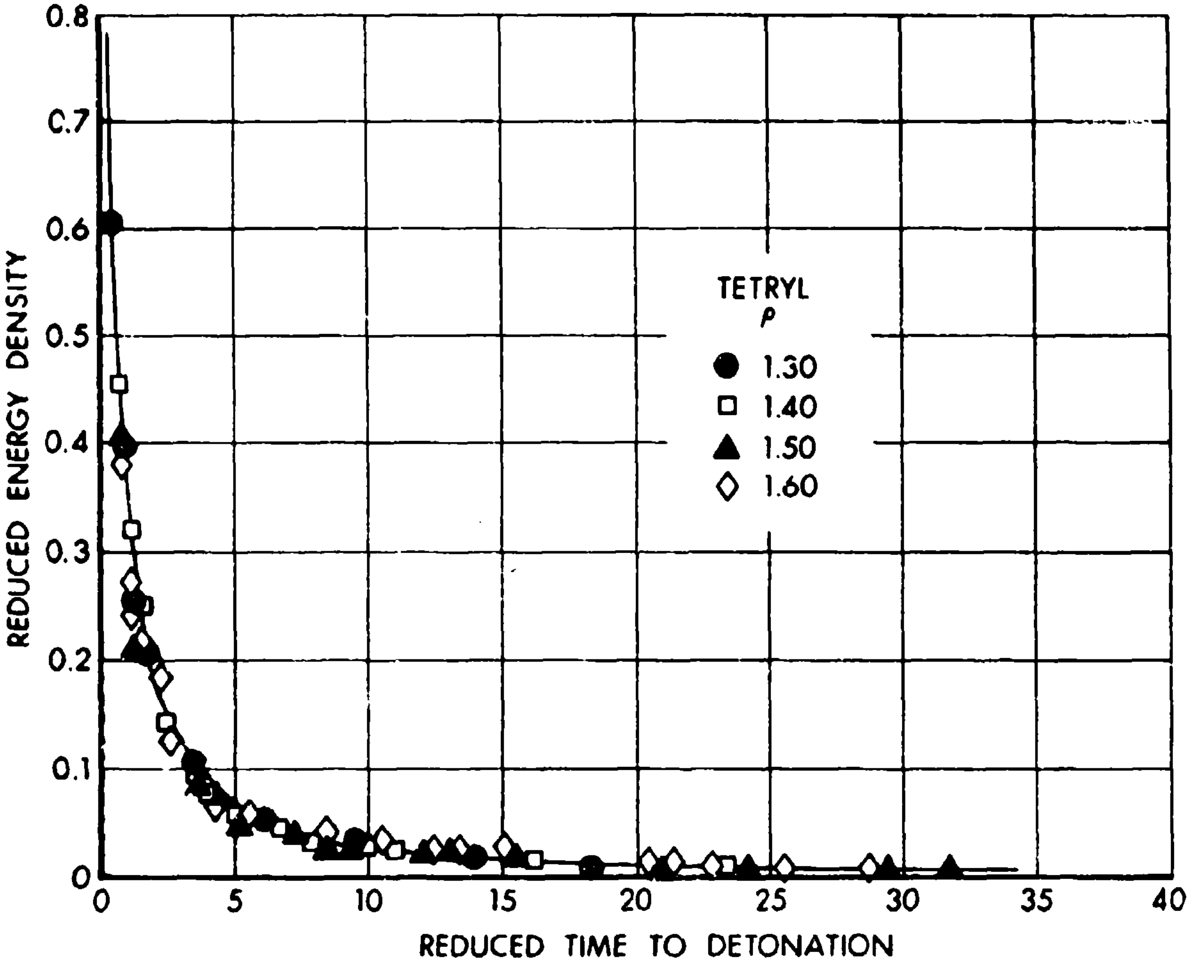

Figure 3. Buildup Data from Fig. 2 (four lower densities) Replotted, Using Scaling Laws. (Ref. 7)

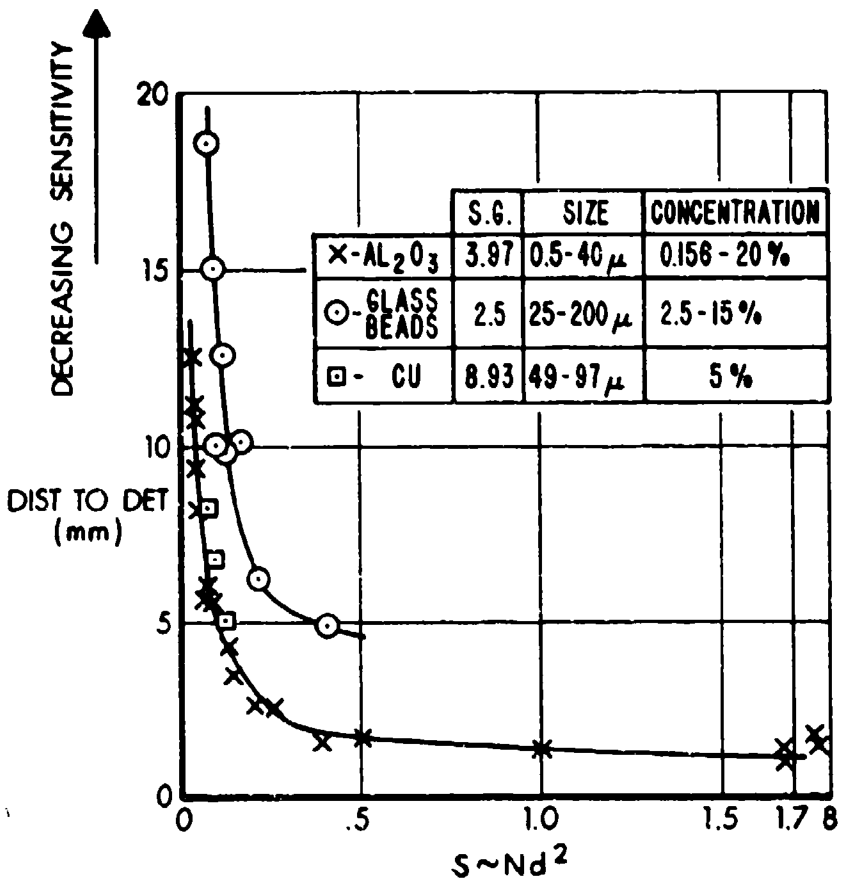

Figure 4. Distance to Detonation Versus Total Inclusion Surface Area for Various Nitromethane/Inclusion Systems. (Ref. 8)

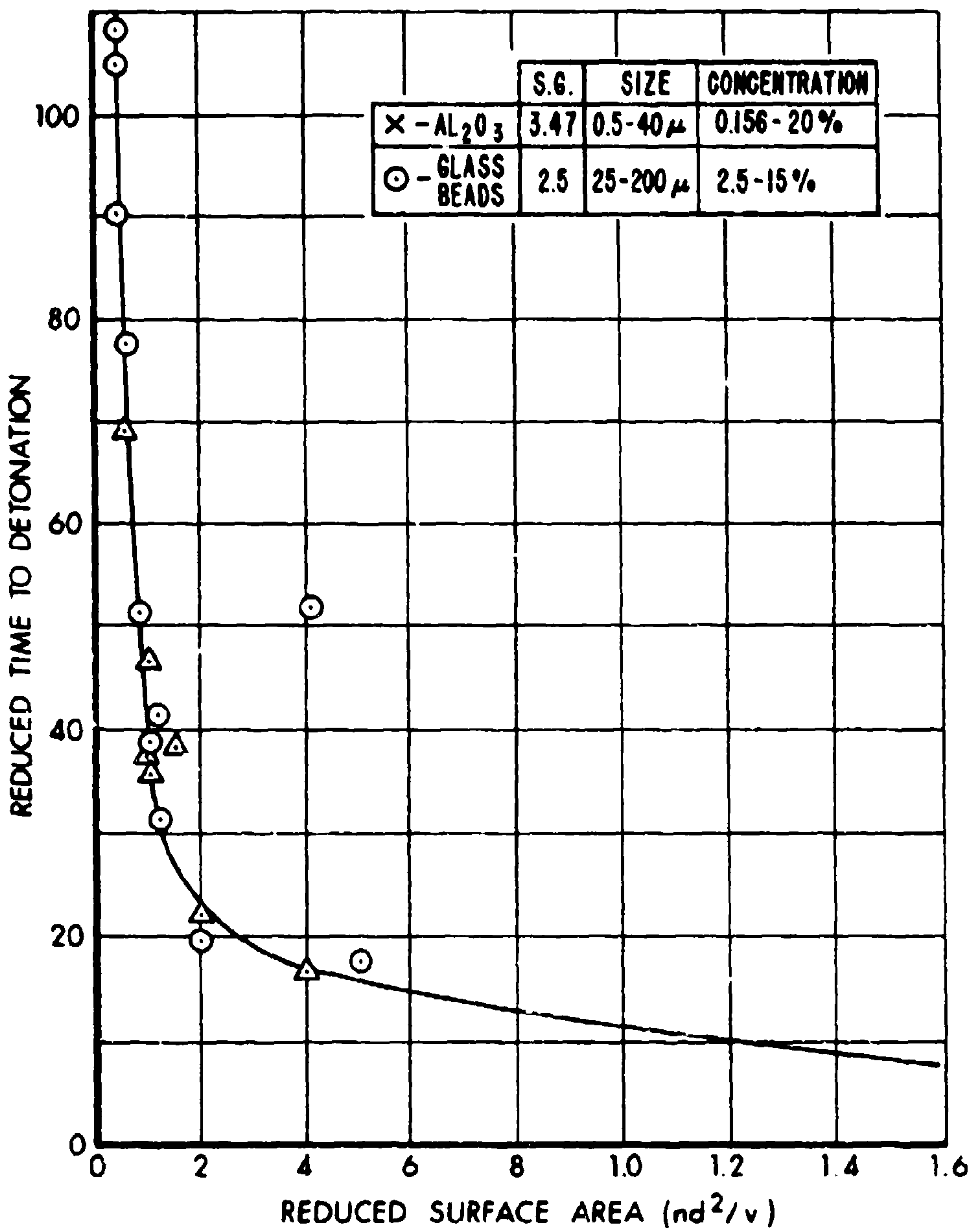

Figure 5. Data from Fig. 4, Replotted to Show Energy Density Scaling. (Ref. 8) Single Off-Curve Data Point is for very Small Diameter Inclusion, and Should not be Expected to Lie on the Curve.

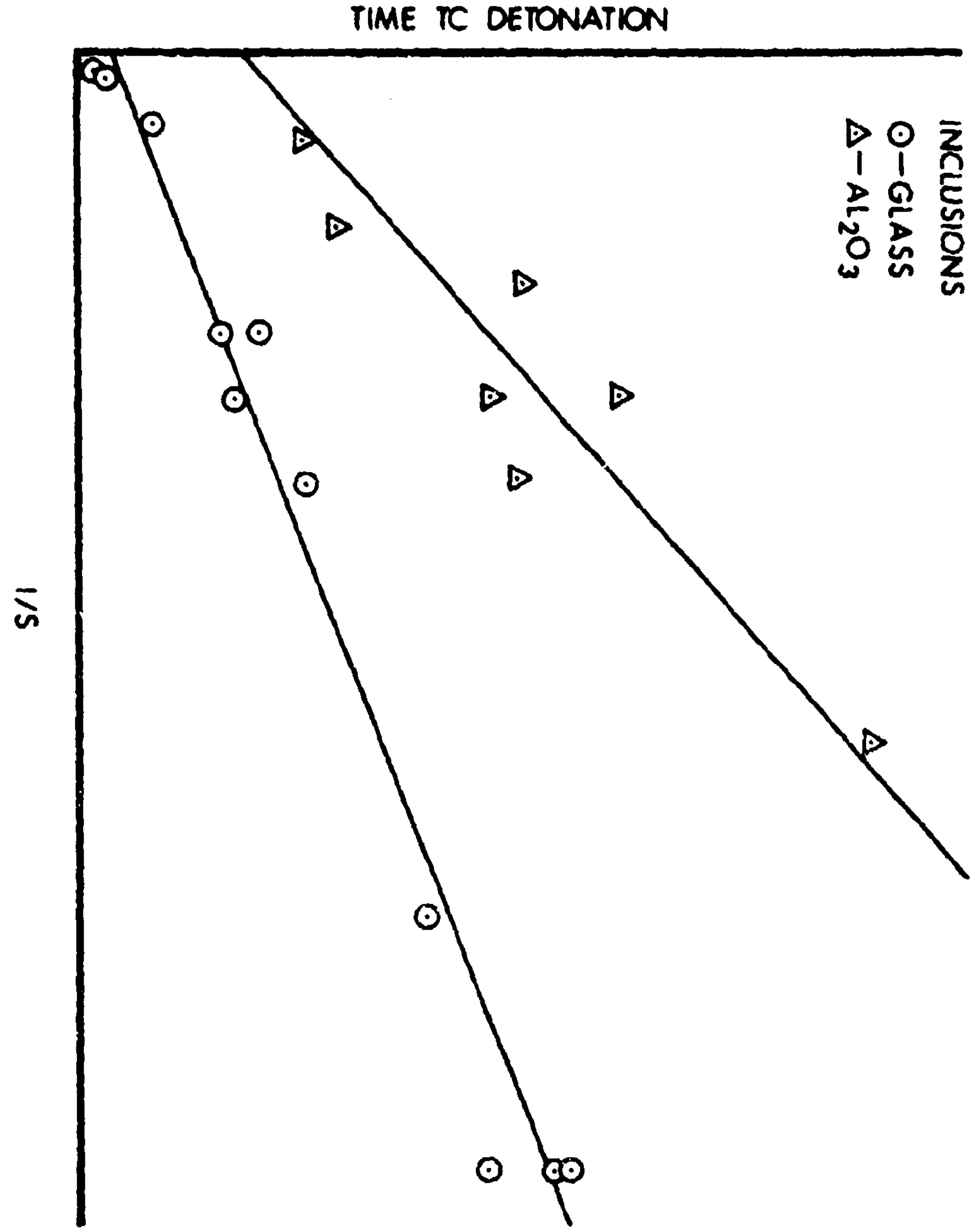

Figure 6. Time to Detonation Versus Reciprocal of Surface Area. Note Linear Relationship.

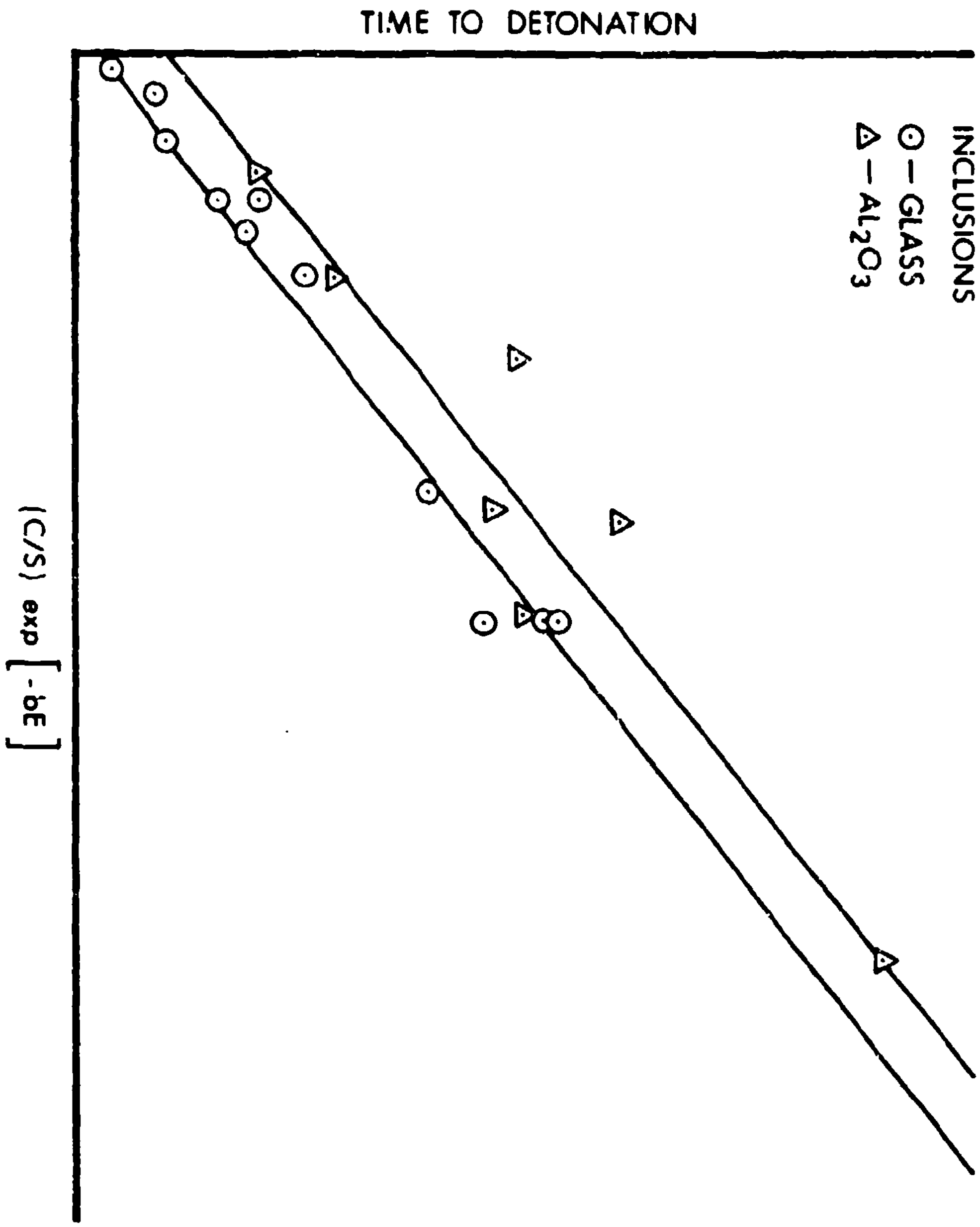

Figure 7. Time to Detonation Versus Reciprocal of Surface Area, Where Energy Density at Hot-Spot has been Included.

DROP-WEIGHT IMPACT SENSITIVITY OF SINGLE CRYSTAL AND POLYCRYSTALLINE EXPLOSIVES

James E. Hole
Terminal Ballistics Laboratory-W, Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

ABSTRACT

The purpose of this work was to determine the sensitivity of single crystals of PETN, HMX, RDX and TNT to impact, and to compare the single crystal impact sensitivities to similar weight samples of polycrystallites. This information was needed to insure safety in handling prior to proceeding in a more detailed program using large single crystals.

Since the results of impact testing in a general way agree with safe handling experience generated over the years, drop-weight impact sensitivity using type 12 tools was chosen to test both single and polycrystalline explosives.

Values determined for 20mg samples were as follows: polycrystalline TNT, 25 cm; HMX, 20 cm; RDX, 30 cm; PETN, 10 cm. The single crystal sensitivity values were lower except TNT, i.e., TNT, 56 cm; HMX, 16 cm; RDX, 18 cm and PETN, 10 cm. For this sample weight, only the single crystals ranked the four explosives in the order normally found in the literature.

The impact sensitivity of TNT was dependent on the sample size. Unexpectedly, it was found that the sensitivity of the polycrystalline explosive increased as the sample decreased. However, the sensitivity of the single crystal explosive decreased as the sample size was decreased.

We concluded that explosive operations with large single crystals of secondary explosives are less hazardous than the operations we presently perform with smaller polycrystalline explosives.

I. INTRODUCTION

The purpose of this work was to determine the sensitivity of single crystals of PETN, HMX, RDX, and TNT to impact and to compare the single crystal impact sensitivities to polycrystalline impact sensitivities of equal weight samples.

This information was needed to insure safety in handling prior to proceeding in processing operations involving blending, transfer by pouring and melt casting of TNT onto large crystals of the other explosives.

Since the results of impact testing in a general way agree with safe handling experience generated over the years, drop-weight impact sensitivity using type 12 tools was chosen to test both single and polycrystalline explosives.

II. PROCEDURE

The explosives chosen for both the polycrystalline and single crystal tests were obtained through Army supply channels and used without purification.

Each explosive was screened through a number 50 sieve (297 micron opening) onto a number 100 sieve (149 micron opening). The screened sample was divided into a portion for the polycrystalline test and a portion for the growing of single crystals. To provide a purity record, differential thermal analysis thermogram (DTA) and selected properties were obtained for each explosive, as shown in Table I.

The single crystals were grown from saturated solutions by evaporation of the solvent. TNT and PETN crystals had the regular crystal habit*[1]. When grown without purification of the starting materials; however, RDX and HMX had the regular crystal habit only from certain containers which were originally made productive by washing with acetone and by the selective removal of crystal agglomerates during the first two evaporations.

The term single crystal is used here to describe a single growing mass with sharp angles and plane faces. When the crystals were estimated to be of the correct weight, they were removed from the solution and dried between filter paper. After the crystals were dry they were weighed and grouped according to size. For each size group of single crystals, twenty samples of polycrystalline explosives with the same weight were weighed into individual containers and stored with the single crystals until it was time to make the impact test.

The drop-weight (impact) apparatus, as shown in figure 1 is a BRL modification of the Bureau of Mines impact apparatus. The apparatus is bolted to a concrete pillar and the tool and impact area are surrounded

*1 (references are listed on page

by an aluminum-framed plastic box to protect the operator, shown in figure 2.

The tools used in this experiment were the type 12 tools shown in figure 3 and described below:

1. Anvil made from Ketos Steel, 59-60 Rockwell C.
2. Anvil support made from mild steel and bolted to base.
3. Plunger guide made from mild steel.
4. Plunger made from Ketos Steel, 59-60 Rockwell C.
5. Replaceable end for drop weight.
6. Drop-weight - 2 kg. size.

The tests were conducted at a room temperature of about 22°C and a relative humidity of 50-70%. The anvil and plunger were changed after twenty drops or less if their surfaces were excessively pitted. Garnet coated sandpaper 180(5/0) grit was positioned on the anvil between anvil and plunger for sandpaper tests.

The anvil area was 7.55 cm^2 and the sandpaper area was 6.45 cm^2. However, the contact area between explosive and anvil was of the order of 0.04 to 0.10 cm^2. The single crystals were oriented with their longest axes facing front to back. Polycrystalline samples were placed in a mound at the center of the anvil.

The initial setting to begin drop testing was taken from the literature*[2] and up-and-down testing was begun at that height setting. Each twenty sample set of the polycrystalline explosive was tested, followed by testing of a twenty sample set of the single crystals. For each drop height the number of explosions and the number of nonexplosions was recorded and used to calculate the height for 50% explosion*[3]. Those explosives for which we had sufficient samples were tested with sandpaper supporting the sample as well as bare metal surfaces.

III. RESULTS AND DISCUSSION

The effect of sample size on sensitivity was examined for polycrystalline PETN and TNT. The results shown in Figure 4, indicated that the sensitivity of polycrystalline TNT increased with decreasing sample weight, whereas polycrystalline PETN remained relatively insensitive. These tests were made with the type 12 tool, with sandpaper, which is the most stringent condition available. The same trends were obtained for the case of TNT without sandpaper.

As the purpose of this effort was to consider the sensitivity of the samples from a hazards standpoint, a 20 mg sample was chosen as a standard size for further tests. This sample size was sufficiently large to permit

precise measurement and ease in handling, while still maintaining a high sensitivity, i.e. lower drop height.

Polycrystalline and single crystal explosives were impacted using a type 12 tool with sandpaper. The data in Table II show polycrystalline and single crystal PETN to be equal in sensitivity. TNT in the same test comparison was less sensitive in single crystal configuration. HMX and RDX single crystals were found to be more sensitive that their polycrystalline counterparts. This was true not only for the 20 mg sample, but also for larger and smaller weight that were tested.

Grit is not an expected contaminant of an explosive; therefore we also tested under less severe conditions by using the type 12 tool bare. The impact height of all four explosives increased. From Table II it is seen that the PETN single crystal is less sensitive than the polycrystallite, but the TNT single crystal is more sensitive than the polycrystallite. The difference between the single crystal and the polycrystallite sensitivity is not distinguishable for either RDX or HMX.

The sensitivity of all the explosive samples tested was such that normal procedures for handling and processing explosives could be followed.

IV. CONCLUSIONS

The order of impact sensitivities using either single crystal or polycrystalline sample remained the same i.e., PETN most sensitive followed by HMX, RDX, and TNT.

A single crystal between bare metal surfaces should not be considered to be supersensitive.

Grit sensitized the single crystals of PETN, RDX and HMX but didn't sensitize single crystal TNT.

Grit supersensitized polycrystalline TNT but it didn't supersensitize any of the other crystals.

Large single crystal sample sizes of PETN, RDX and HMX were found to be less sensitive.

For single crystal HMX and PETN, explosion on impact was achieved without grit and without apparent internal voids.

For single crystal RDX 98.9% TMD, and TNT 99.4% TMD absence of internal voids, explosion was achieved without grit.

The sensitivity of all the explosive samples tested was such that normal procedures for handling and processing explosives could be followed

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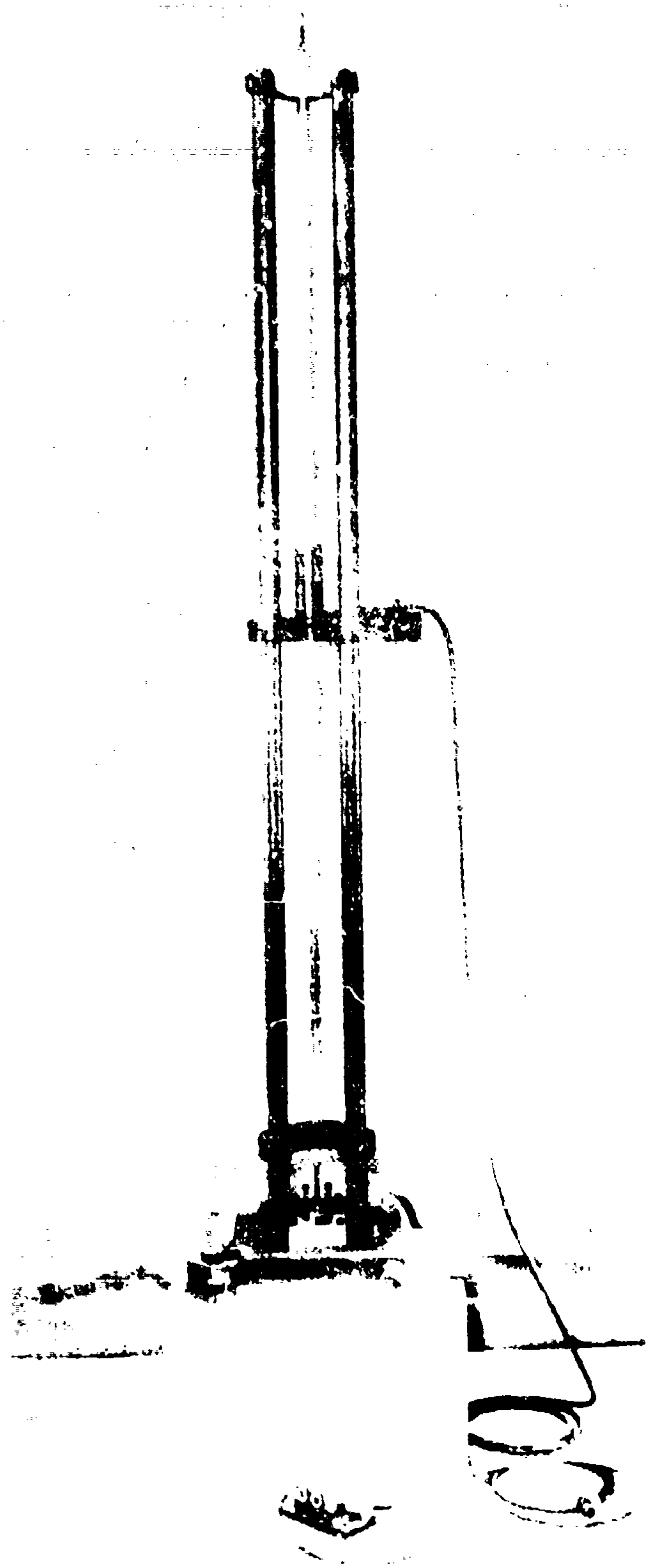
TABLE I

SELECTED PROPERTIES OF THE EXPLOSIVES

	Density, g/cc				
Explosives	TMD	Actual Bulk	%TMD	Actual Crystal	%TMD
PETN	1.77	.68	38	1.77	100
RDX	1.82	.91	50	1.80	98.9
HMX	1.90	.75	39	1.90	100
TNT	1.65	.83	50	1.64	99.4

Fig. 1 BRL Sensitivity Apparatus



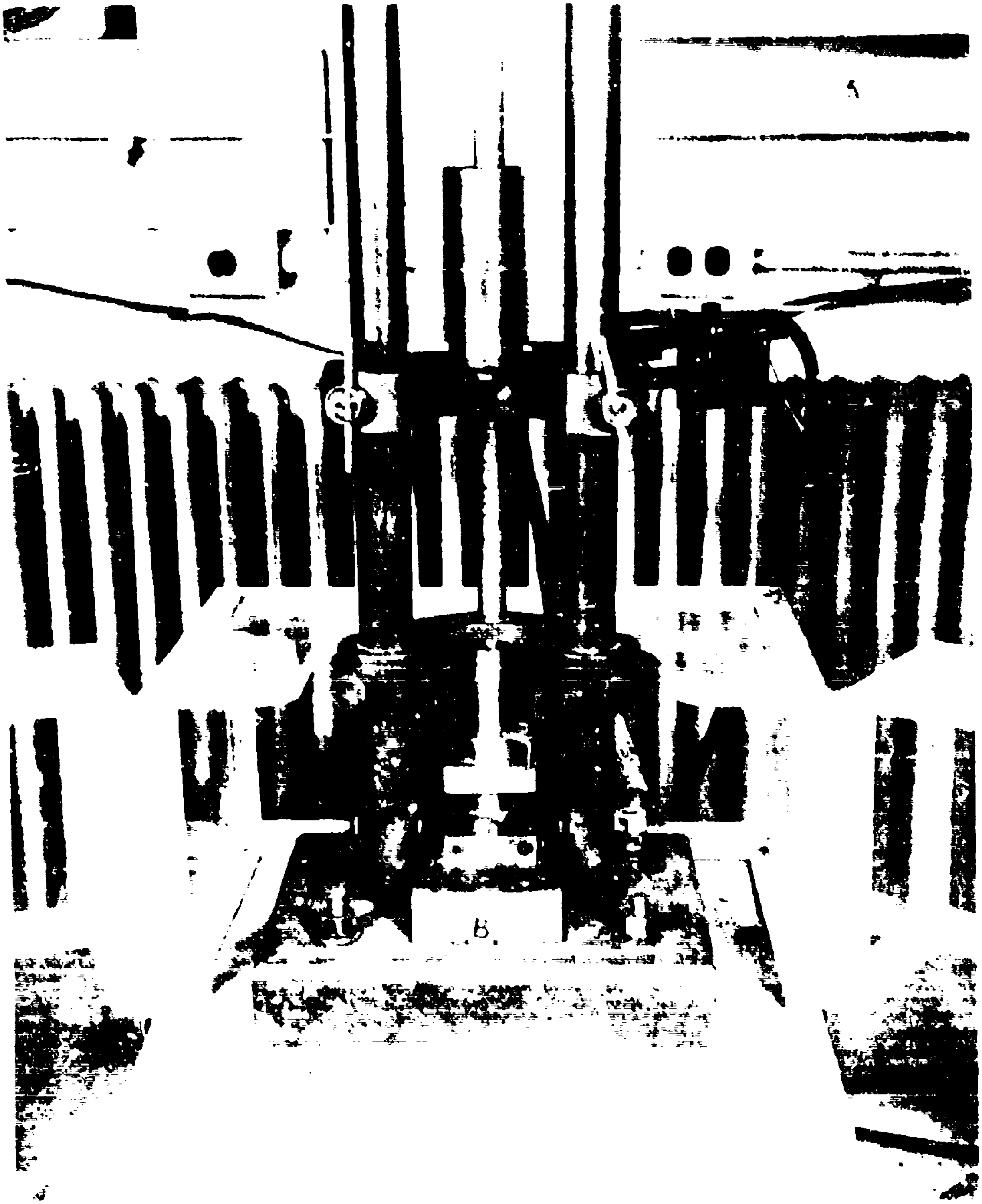

B.

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Figure 3.

[illegible]

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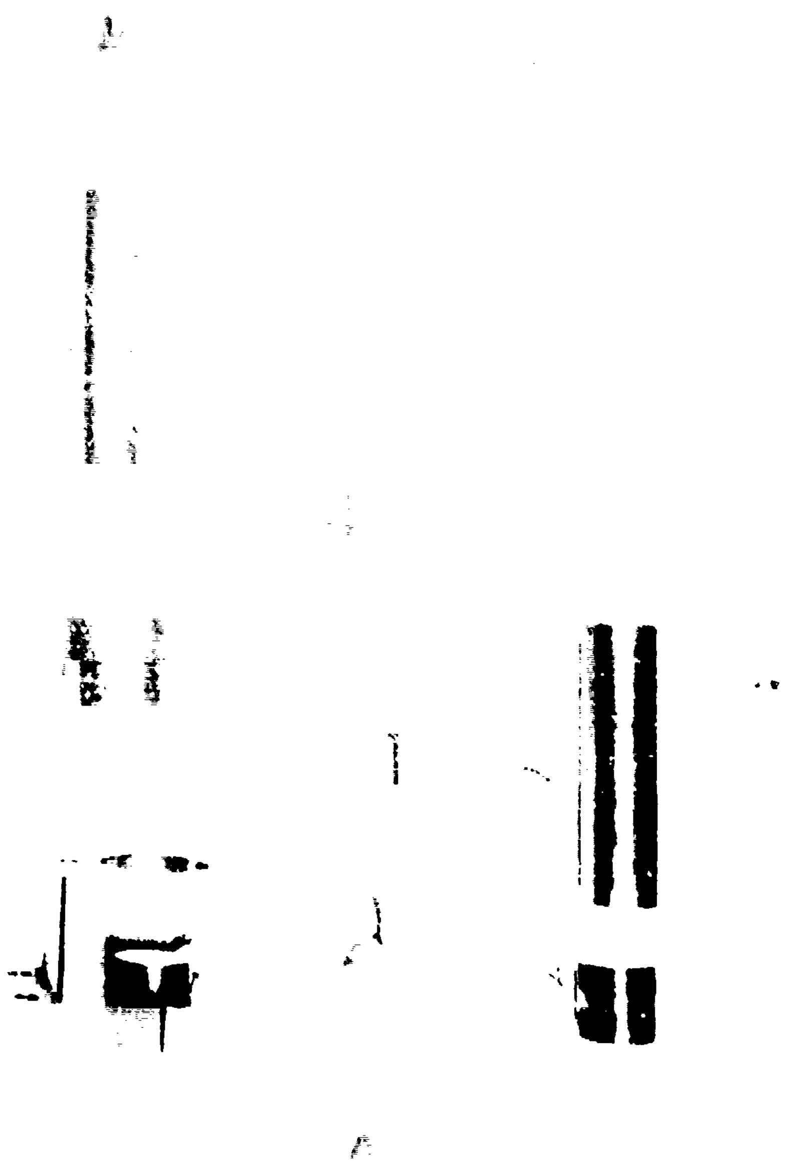


FIGURE 4 - EFFECT OF SAMPLE WEIGHT ON IMPACT HEIGHT

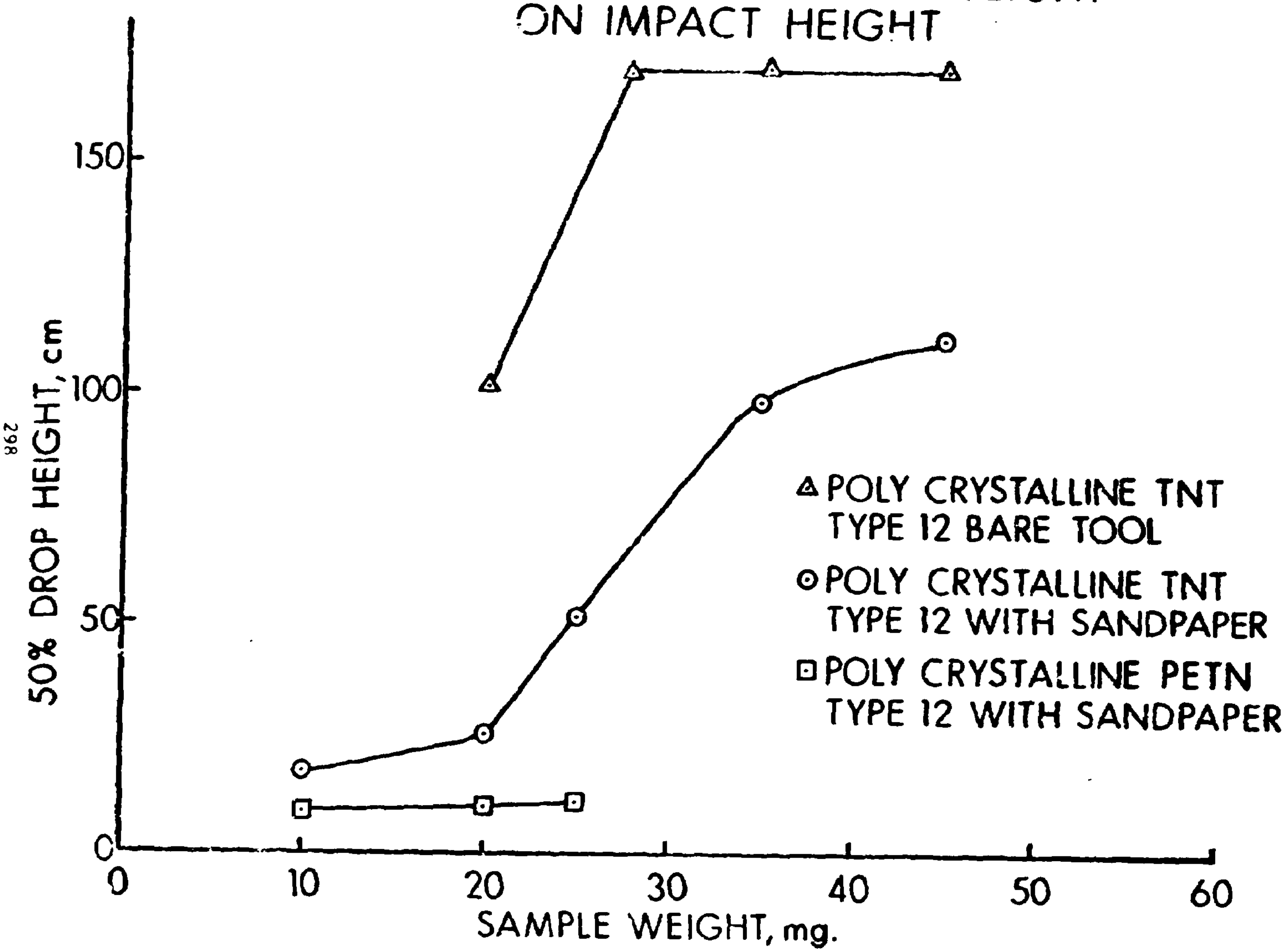


TABLE II

50% Drop-Height, cm Using Type 12 Tool

Explosives	Bare Tool Sample wt. 20 mg.	Sample set on sandpaper 5mg.	10mg.	20mg.	25mg.	30mg.	35mg.	45mg.	N*	L**
PETN										
Poly	15		9	10	11				12	11
Single	33		7	10						
RDX										
Poly	46		27	30					24	28
Single	43	8	10	18		23				
HMX										
Poly	33		30	20					26	29
Single	33		13	16		20				
TNT										
Poly	102		18	25	51		98	112	157	76
Single	53		81	56						

* Naval Ordnance Laboratory, White Oak, Md. 35mg. sample, 2.5kg wt (5)
** Lawrence Radiation Laboratory, 35mg. sample, 5kg wt (5)

SENSITIVITY MEASUREMENTS OF AN ENCAPSULATED LIGHT-SENSITIVE EXPLOSIVE

by

A. B. Wenzel
Southwest Research Institute
San Antonio, Texas

I. INTRODUCTION

During the fall of 1969, staff members of the Department of Mechanical Sciences at Southwest Research Institute (SwRI) embarked on an in-house program to investigate if light-initiated silver acetylide-silver nitrate (SASN) could conceivably be used to initiate a less sensitive but more powerful explosive, retaining the good simultaneity of ignition of the SASN and utilizing the higher pressures and impulses possible with more powerful explosives. We investigated this possibility using pentaerythritol tetranitrate (PETN) as a secondary explosive. As in all the experiments conducted under our internal research projects, the efforts were exploratory in nature and were terminated when we felt we had demonstrated the feasibility of the process. Extensive experiments were made in spray-depositing the PETN to obtain uniform density coatings. It was found that PETN can be sprayed in a supersaturated solution of acetone, or by using carbon tetrachloride or any of the several straight chain or ring type hydrocarbons as carriers. Some binder was needed to strengthen the sprayed or cast film. Carbon tetrachloride-Elvax-PETN resulted in a good mixture for casting or spraying. This mixture sprayed well and the coating produced was fairly strong and dense. Reliable detonations were obtained with coatings requiring at least 25 mg/cm^2 of silver-acetylide. Impulsive levels up to about 30 kilotaps were measured with Valpey quartz pressure transducers to determine pressure ranges of this PETN system. This transducer only records for 866 nanoseconds, and peak pressures at the end of this period were recorded as high as 10 kilobars. We felt that the feasibility of this technique for achieving high level impulses with good simultaneity of initiation over large areas had been demonstrated with these experiments, and therefore terminated this phase of the project.

In March of 1970, a test was conducted for the purposes of demonstrating that high impulses can be imparted explosively to the surface of a structure using an explosive train of SASN and PETN. The primary explosive, SASN, was initiated by intense light flash, in the manner developed at SwRI. Although this demonstration experiment was conducted using a sample with small area (3 x 3 in^2), excellent simultaneity of detonation of the PETN was achieved and should be possible to be used over much larger areas.

The recovered aluminum plate showed a dense smoke trace pattern over the 3 x 3 in^2 area covered by the SASN, indicating submicrosecond simultaneity of detonation over this area. The PETN detonated completely, and considerably enlarged the cavity in the plate as a result. The plate gave every appearance of excellent simultaneity of initiation of the PETN. The total specific impulse as measured with a ballistic pendulum was 11.3 kilotaps.*

The purpose of this simple experiment was to demonstrate that impulses in excess of 100 kilotaps can be obtained from the combination of a layer of SASN over PETN. There is no fundamental reason why higher impulses could not be easily obtained, simply by employing thicker layers of PETN. Similarly, there is no fundamental reason why other secondary explosives such as Composition B, Pentolite, TNT, etc., cannot be initiated with this combination.

From these preliminary investigations, it was felt that an efficient plane wave generator could be developed from a SASN-PETN combination. Under sponsorship from the Ballistic Research Laboratories, SwRI is currently working on a program, the objective of which is to generate a plane wave lens using SASN-PETN combination, and to demonstrate that the lens will initiate a steady-state detonation in a secondary explosive such as Composition B or Octol.

To safely handle the plane wave generator in the laboratory, it was necessary to develop a SASN formulation which would be safe to handle and whose sensitivity to friction and impact is reduced from the present SASN formulation while maintaining its light initiation. Additionally, these new SASN formulations should not be sensitive to flash irradiation (as when a 200-watt incandescent light bulb at 1 ft from the charge, burns out), nor to direct sunlight. To accomplish this, various samples of a plasticized polymer silver acetylide solution containing various ratios of explosive-to-binder were prepared. Light-absorbing dyes were introduced to improve the quantum yield of the activating light and optimize the simultaneity of ignition. The criteria for sensitivity of the new encapsulated SASN formulation were that it should be no more sensitive to friction, static electricity, or impact than PETN.

This paper discusses the experimental tests and the results obtained in measuring the sensitivity of an optimized encapsulated SASN formulation to flash irradiation, impact, friction, and static electricity. These were then compared to similarly conducted sensitivity measurements for PETN. This paper does not discuss the chemistry of the various SASN formulations nor does it cover the specific performance of the plane wave generator. The latter is a subject of current investigation.

*1 tap = 1 dyne-sec/cm

II. SENSITIVITY TESTS

A. Flash Irradiation of a 200-Watt Incandescent Light Bulb

In order to determine the sensitivity of the encapsulated and pure SASN to flash irradiation of a 200-watt incandescent light bulb at a 1-ft distance from the test sample, a number of specimens of pure SASN and encapsulated SASN were prepared and tested under these conditions. The results of the tests are reported in Table I.

TABLE I. 200-WATT FLASH IRRADIATION TESTS

Explosive	Sample	No. of Flashes	200-Watt Bulb (Type)	Voltage	Bulb Burnout	Distance (ft)	Detonation	Effect
SASN (troweled)	A	1	Sylvania	210	yes	1	no	none
		2	"	230	"	"	"	"
	B	1	"	210				
				220				
				230	"	"	"	"
Encapsulated SASN (troweled)	A	1	"	230	"	"	"	"
		2	"	230	"	"	"	"
	B	1	"	230	"	"	"	"
		2	"	230	"	"	"	"
Encapsulated SASN (sprayed)	A	1	"	230	"	"	"	"
		2	"	230	"	"	"	"
	B	1	"	230	"	"	"	"
		2	"	230	"	"	"	"

In every instance, both the pure SASN and the encapsulated SASN proved to be insensitive to this flash irradiation. The top surface was not affected. Direct sunlight tests were not conducted. However, previous sunlight tests conducted by SwRI several years ago also showed that pure SASN was insensitive to direct sunlight. Direct sunlight will blacken the top surface of the explosive while leaving the under layer intact.

B. Impact Sensitivity Tests

The impact sensitivity tests were conducted with the apparatus shown in Figures 1 and 2. The basic parameters of this apparatus include an approximate 8-lb plummet which can be released from any height up to 39 inches.

FIGURE 1. IMPACT SENSITIVITY TEST APPARATUS

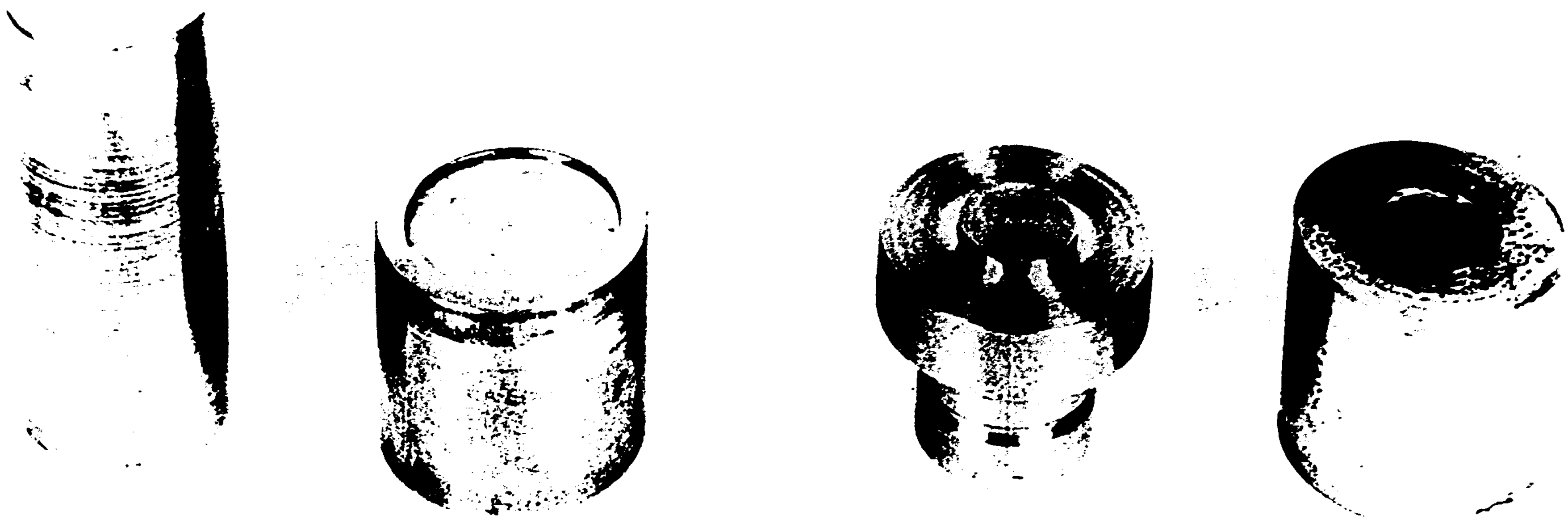


FIGURE 2. LARGE AND SMALL STRIKER AND SPECIMEN CUP FOR IMPACT TESTS

The impact force is transmitted through a striker pin (Figure 2) to the specimen resting in the specimen cup, also shown in Figure 2. The plummet is guided through polished steel guide rails onto the striker pin and specimen cup.

In this report, impact sensitivity is expressed in terms of the drop height at which the test material has a 50% probability of reaction. This drop height is called, for brevity, the "50% point." The test method by which the 50% point is obtained is known as the "up-and-down" or "Bruceton" method, described in detail in References 1 and 2. Briefly, it involves a predetermined number of test drops made from varying heights (in equal log increments) in such a manner as to bracket the 50% point of the test material. Recently, Dixon (Ref. 3) has described the application of this method with small samples (e.g., sample size of $N \leq 6$) and this method was utilized in this program. Figure 3 shows a typical test data sheet. In this figure, the symbols X and 0 indicate reaction and nonreaction, respectively.

It should be noted that, in conducting an impact sensitivity test, one must assign a value of "positive" to test results if any evidence of reaction is found, regardless of the severity. This means that a test drop yielding a slight "pop" is assigned the same value as one yielding a violent detonation. Clearly, a material which yields only mild reactions under a given energy input is less hazardous than one yielding detonations under the same conditions. By definition, however, an impact sensitivity test could not evaluate this difference quantitatively. Thus, a reaction intensity test utilizing pressure monitoring devices is necessary for complete hazards evaluation. However, for this program, the reaction intensity tests were not conducted because the determination of relative hazard of a complete detonation of either PETN or SASN is well understood.

During these tests, two sizes of strikers and specimen cups were used. The difference in the cup and the striker design is illustrated in Figure 2. Initially, the experiments were conducted using the large striker and specimen cups, primarily because of previous SwRI experience in utilizing this setup. However, as can be seen from the results given in Table II, the exact impact sensitivity for PETN and the encapsulated SASN was not obtained because to do so required a higher height than the apparatus allowed. Therefore, it was decided to design new specimen cups to strikers having relatively smaller area and more confinement in the hopes that this would make some difference in the impact sensitivity. As shown in Table II, this change did make some difference on the impact sensitivity of pure SASN and the encapsulated SASN, but it did not make any difference on the PETN. Also, an anomaly occurred using the smaller cups because the data indicate that the encapsulated SASN was more sensitive to impact than the pure SASN. This difference did not occur when using the larger cups. However, because the method for calculating the 50% point applies the logarithm of the drop height, comparing this difference in a logarithmic form shows that SASN

IMPACT SENSITIVITY TEST

Sample Encapsulated SASN Date 27 April 1973

Temperature 80°F Humidity 45% Operator M Rumbaugh

Test Drop No.

Drop Ht.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	X's	O's
38.0"																											
30.2"	X																									1	0
24.0"		X		X		X								X		X										5	0
19.0"			O		O		X				X		O		O		O									2	5
15.1"								X		O		O														1	2
12.0"									O																	0	1
9.5"																											
7.6"																											
6.0"																											
																									Total	9	8

ANALYZE "O":

Drop Ht.	i	N_i	$i\,N_i$
	5		
30.2"	4	0	0
24.0"	3	0	0
19.0"	2	5	10
15.1"	1	2	2
12.0"	0	1	0

N = 8 A = 12

50-percent Point:

$$\bar{X} = \log(\text{lowest drop ht.}) + 0.1\left(\frac{A}{N} \pm \frac{1}{2}\right)$$

$$= 1.0792 + 0.1\left(\frac{12}{8} + \frac{1}{2}\right)$$

Antilog $\bar{X}$ = 19.0 in.

FIGURE 3. SAMPLE IMPACT SENSITIVITY DATA SHEET

TABLE II. IMPACT SENSITIVITY RESULTS

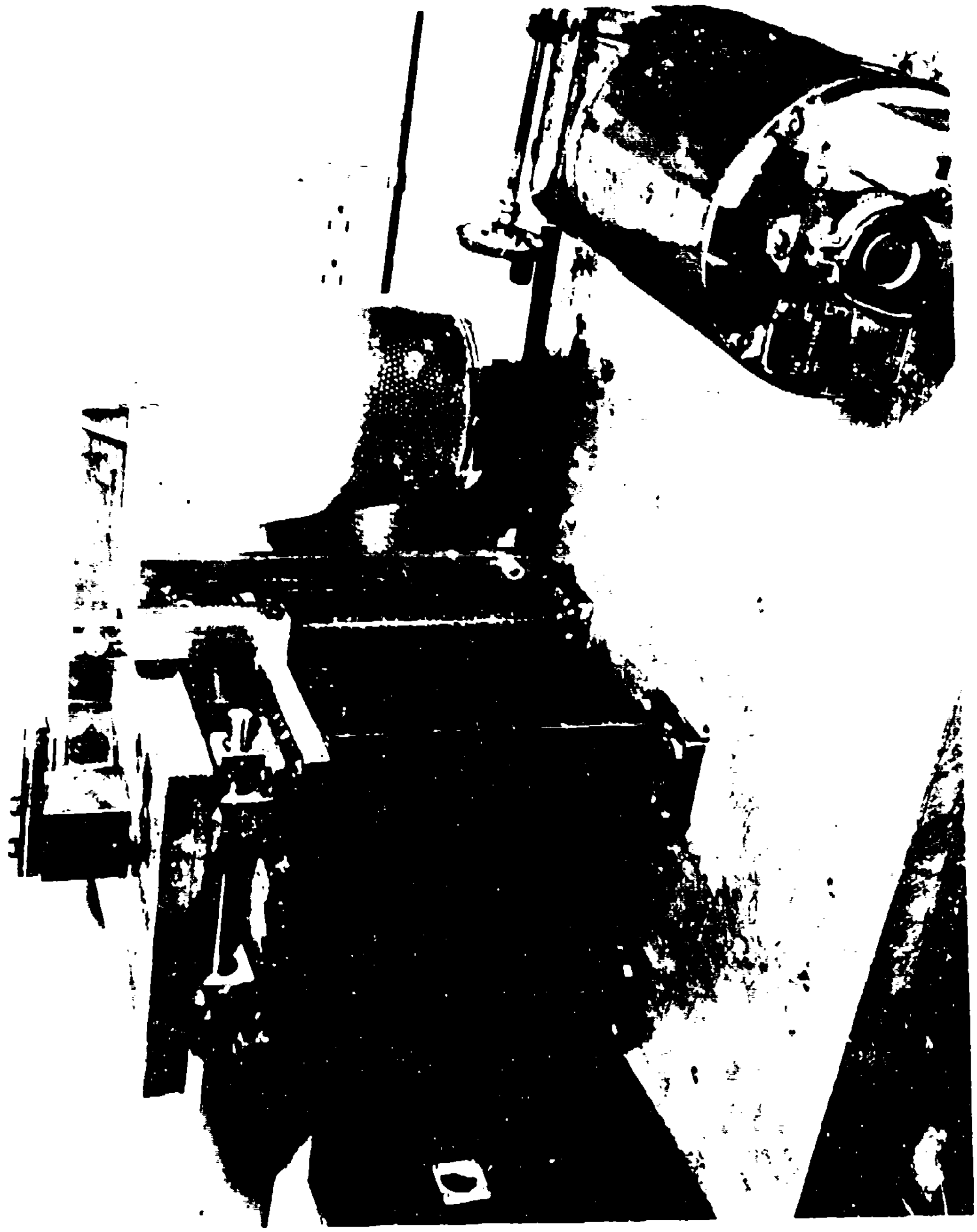
Test No.	Explosive Material	Number of Drops Large Cup	Small Cup	Sensitivity (in.)
1	Pure SASN	7	--	30.5
2	Encapsulated SASN	20	--	>38.0
3	PETN	10	--	>38.0
4	Pure SASN	--	9	26.8
5	Encapsulated SASN	--	17	19.0
6	PETN	--	7	>38.0

and encapsulated SASN values were of the same order of magnitude and not significantly different. Therefore, one can conclude that although the SASN and encapsulated SASN are more impact-sensitive than PETN, the differences are not large. Considering that the PETN (the referenced material) is not dangerously sensitive for laboratory uses when applying standard safety precautions, the SASN and encapsulated SASN can also be handled relatively safely for laboratory use if the same safety precautions are utilized.

C. Friction Sensitivity Tests

The friction sensitivity tests were conducted utilizing a SwRI design apparatus illustrated in Figure 4. The basic components of this apparatus consist of a variable speed drive unit, a rocker plate to which a friction surface has been rigidly attached, a specimen holder which is sandwiched between the rigid friction surface and a moment arm for which various weight loads are placed to vary the frictional forces. The maximum stroke of the rocker plate is approximately 1/2 inch. The variable drive unit was set to rock the base plate at a rate of 420 strokes per minute.

The objective of these tests was to obtain a comparative measure of the sensitivity of pure SASN, encapsulated SASN, and PETN. This comparative number was to be obtained by a measure of the load applied to the moment arm. Figure 5 shows a closeup of the test specimen holder used during this series. Note from Figure 4 that one specimen holder was grooved and the other had sandpaper attached to it. The first series of tests was conducted using the grooved test specimen holder. This holder was designed to retain the explosive within the grooves during the stroking operation. In reality, however, this holder proved to be very inefficient because most of the explosive was spread beyond the grooves during the first stroke of the



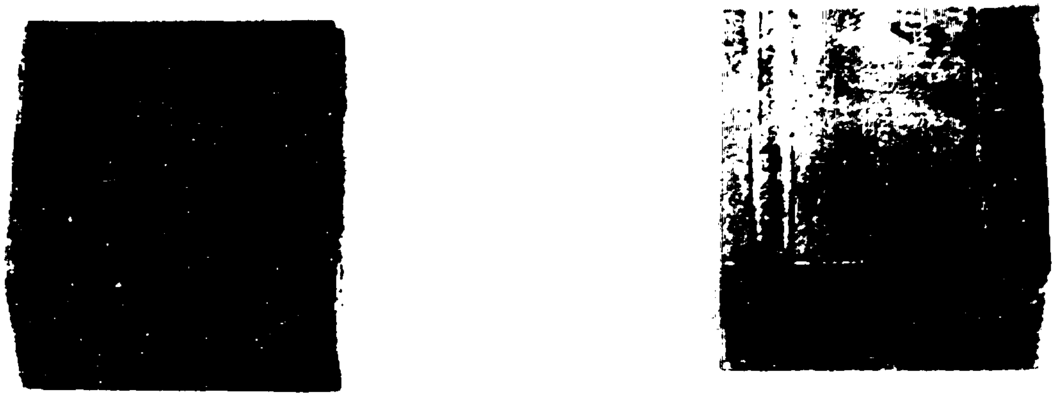


FIGURE 5. FRICTION TEST SPECIMEN HOLDER

operation. Furthermore, using 20-lb weights on the moment arm failed to get any reaction from the explosive during a 10-sec. test period. Therefore, this specimen holder was modified by placing silicon carbide 400-grid sandpaper on the surface of this test specimen. Pure SASN, encapsulated SASN, and PETN explosive specimens were tested with this configuration. The test conditions and results are given in Table III. Note that no detonations occurred with any of these explosives, indicating that all of these materials are relatively insensitive to friction. Also, note from Table III that the frictional forces applied in these experiments were sufficiently high to wear the grid surface of the sandpaper off, producing a glazed area in the center of the test specimen.

From the results obtained above, there was some additional concern by the SwRI staff that perhaps if the explosive were contained in an elastic medium for longer periods of time, different results might occur. Therefore, test specimens were prepared where 3/10 gram of each one of the types of explosive considered in the previous tests was introduced into a latex rubber tubing approximately 0.125 in. I.D. and hand-tamped into a given volume which was then sealed by tying a knot into the end of the tube, as illustrated in Figure 6. This test specimen was then taped to the upper friction surface of the apparatus and placed between this friction surface and a plane steel test specimen holder. A 20-lb weight load was used for all of these tests, and the results are reported in Table IV and illustrated in Figure 6. Note that, from the results given in Table IV, no detonation occurred for any of the specimens. However, increasing discoloration of the two occurred with increasing running time, as shown in Figure 6. This discoloration may indicate a thermal decomposition in the explosive.

It was concluded from these tests that PETN, pure SASN, and the encapsulated SASN were relatively insensitive to friction and could be handled with relative safety in a laboratory.

D. Spark Sensitivity Tests

To determine the spark sensitivity of the encapsulated SASN as compared to pure SASN and PETN, a spark generating apparatus was assembled capable of discharging a 0.5 μfarad capacitor through a step-up transformer (automobile ignition coil). The apparatus had a variable voltage range from 0 to 350 volts as measured across the firing capacitor. A high-voltage electrode was positioned directly above the sample at a constant air gap of 0.100 in. to discharge a spark through the test sample into a ground surface. The voltage was monitored by a volt-ohm meter. Figure 7 illustrates this apparatus showing the positioning of the electrode relative to the test specimen. Figure 8 illustrates typical test specimens.

The results of the spark sensitivity tests are summarized in Table V. The detonation threshold voltage was determined by discharging through a

TABLE III. FRICTION SENSITIVITY TESTS USING SANDPAPER

Test No.	Material	Quantity (grams)	Dead Weight (lb)	Stroke Rate (strokes/min.)	Results
1	SASN	0.1	19.93	420	Sandpaper rubbed from plate on 1st stroke. Test ran for 60 seconds. No detonation.
2	"	"	10.01	"	No detonation. Test stopped at 378 seconds due to a machine malfunction. Sandpaper remained in place. There is a slack area (about 1/2" diam.) in centor of the lower plate.
3	"	"	12.10	"	No detonation. Test stopped at 41.5 seconds due to a machine malfunction. There is again a dark area in the center of the lower plate. Sandpaper is slightly wrinkled on one side.
4	Encapsulated SASN	"	10.01	"	No detonation. Test stopped at 30 seconds. There is a dark glazed area in the center of the block.
5	"	"	"	"	No detonation. Test stopped at 30 seconds. Same comments as for Test #3.
6	"	"	"	"	No detonation. Test stopped at 30 seconds. Dark area created and sandpaper pushed halfway from plate.
7	"	"	"	"	Same comments as for Test #6.
8	PETN	"	"	"	No detonation. Test stopped at 30 seconds. Sandpaper almost completely pushed from plate.
9	"	"	"	"	No detonation. 30 seconds.
10	SASN	0.3	"	"	No detonation. Test stopped after 60 seconds. Sandpaper still in place. Center of plate is darkened and glazed.

NOTE: All explosive specimens were oven dried for 2 hrs prior to start of the test. Approximate oven temperature is 130°F. Carborundum "Fastcut" waterproof No. 400 silicon carbide paper was glued to the lower friction plate only, using 3M brand "77" spray adhesive. Humidity in the test area was 55%, and the temperature was approximately 76°F. The explosive was loosely piled in the center of the lower friction plate after weighing.

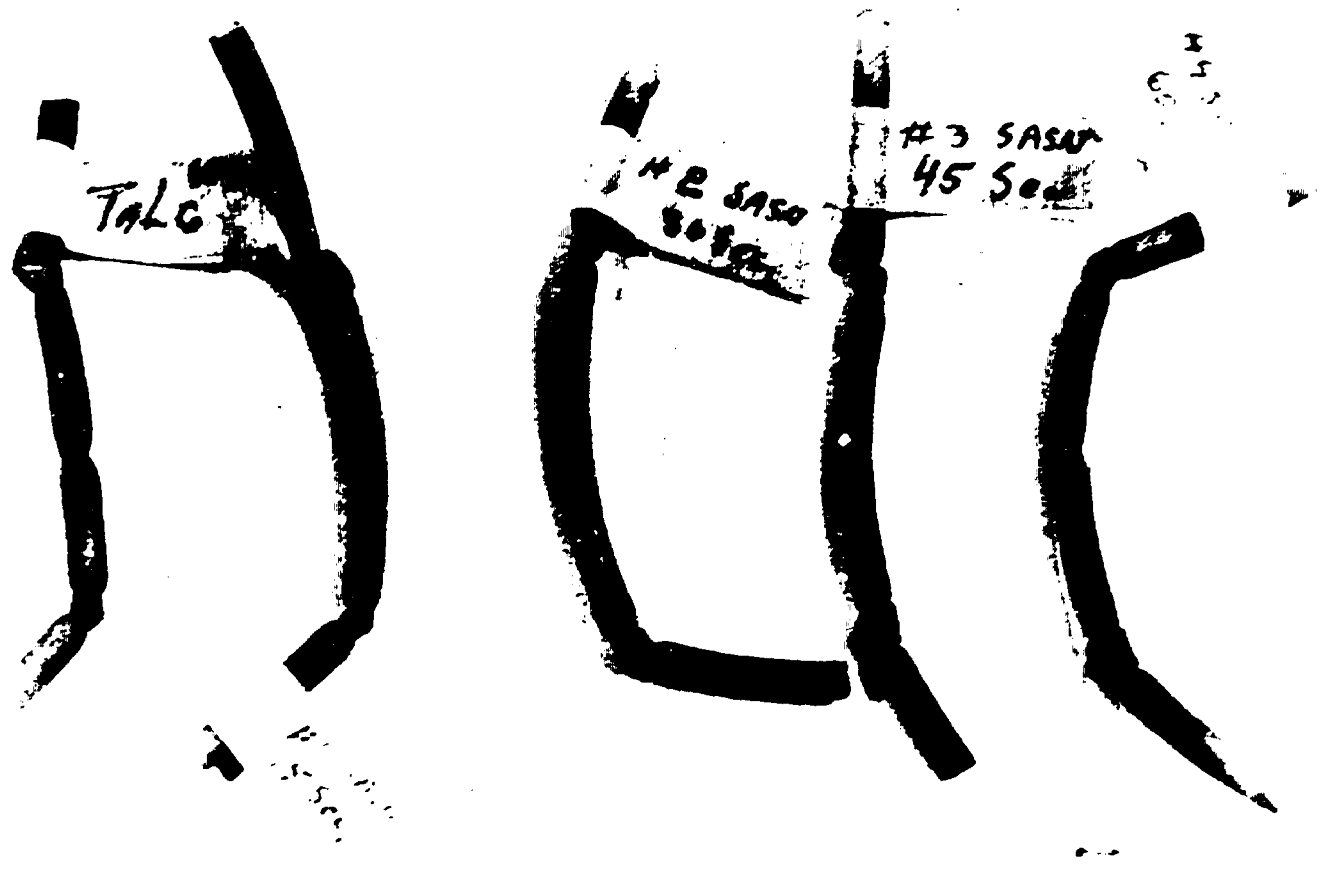
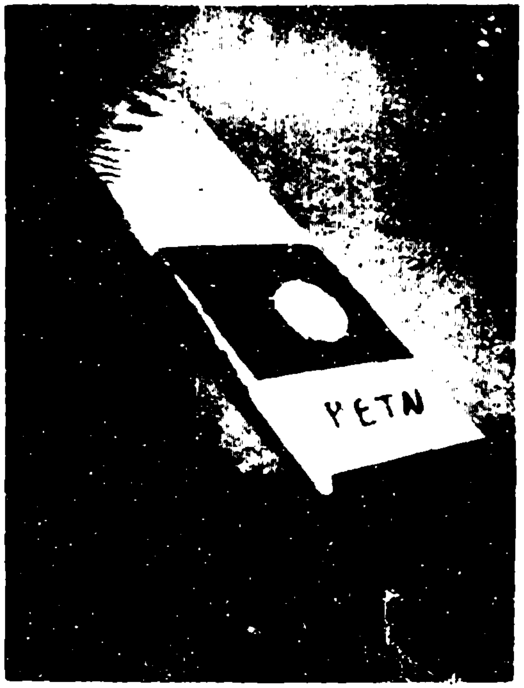


FIGURE 6. SASN FRICTION TESTS CONFINED IN RUBBER TUBING

Overall View

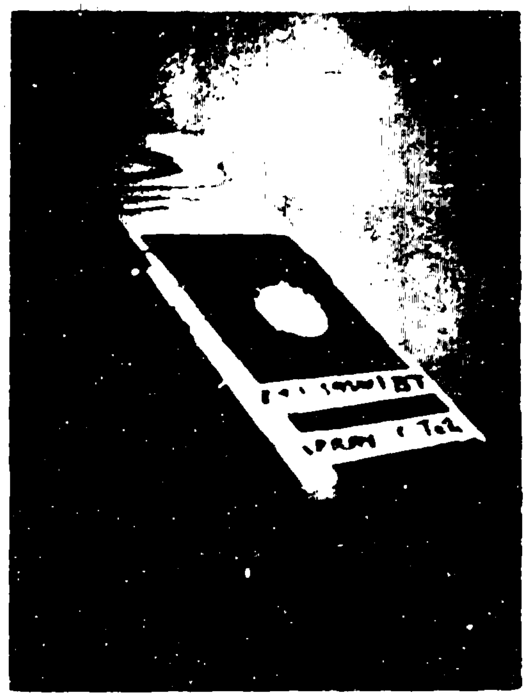
Close-up View of Test Specimen

FIGURE 7. SPARK TEST APPARATUS



PETN Trowled Specimen

(1" Diameter x 0.062" Thick)



24 : 1 SASN-BT Sprayed Specimen

(1" Diameter x 0.062" Thick)

FIGURE 8. TYPICAL TEST SPECIMENS

TABLE IV. ADDITIONAL FRICTION TESTS

Test No.	Material	Quantity (grams)	Length of Packed Tube (in.)	Running Time @410/min.	Results
1	SASN	0.3	1-7/8	15 sec	Discoloration of tube--dark red.
2	"	"	2	30 sec	" "
3	"	"	1-7/8	45 sec	Discoloration of tube--darker red.
4	"	"	2	60 sec	Discoloration of tube--darker red & tube leaking.
5	Encapsulated SASN	"	1-3/4	15 sec	Slight discoloration of tube.
6	"	"	"	30 sec	" "
7	"	"	2	45 sec	Greater discoloration of tube.
8	"	"	1-5/8	60 sec	Greater discoloration of tube & tube leaking.
9	PETN	"	1-3/4	15 sec	Small cut in tube. No discoloration.
10	"	"	1-7/8	30 sec	Slightly black area on tube.
11	"	"	1-3/4	45 sec	Tube cut & slightly black.
12	"	"	1-7/8	--	Tube cut in half at 51.5 sec.

test sample at incremental voltage levels. A minimum of 20 spark attempts was made at each voltage level before increasing the applied voltage. This procedure was repeated until detonation occurred. In the majority of the cases, detonation did not occur during the first spark attempt at the threshold voltage level, and the attempt number at which detonation did occur is shown in the eighth column of Table V. It is believed that in the case where detonation occurred after a high number of attempts, especially in the troweled specimens, the spark followed the path of least resistance through cracks in the explosive sample, rather than passing through the explosive. In analyzing the results summarized in Table IV, the following observations can be made:

(1) Both SASN and encapsulated SASN are considerably more sensitive to spark than PETN. This is based on the fact that PETN did not detonate at the maximum voltage of our apparatus which can deliver, assuming no losses in the system, a maximum energy of 0.03 joules. Published data on spark sensitivity of PETN indicate that PETN will detonate at approximately 0.06 joules.

TABLE V. SPARK SENSITIVITY TESTS

Type of Explosive	Method of Application	Approximate Thickness of Explosive (in.)	Air Gap (in.)	Humidity (%)	Detonation Threshold Voltage	No. of Test Where Detonation Occurred	Remarks
SASN	troweled	0.062	0.10	50	115	4	
Encapsu-lated SASN				52	110	17	
"				53	130	1	
"				53	>350	--	No detonation observed at maximum voltage of 350 V after 20 tries.
"				54	200	1	
"					>350		No detonation after 20 tries.
"					350	2	
"					300	2	
"	sprayed			55	125	1	
"	troweled			66	210	8	
"				61	>350		No detonation at maxi-mum voltage after 20 tries.
"					300	1	
"					>350		No detonation at maxi-mum voltage after 20 tries.
"	sprayed			63	140	3	
				63	140	2	
PETN	troweled			56	>350		No detonation at maxi-mum voltage after 20 tries.

(2) Comparing SASN to encapsulated SASN, the results are inconclusive. This is based on the fact that in some cases there appeared to be no difference between the threshold voltage levels of the two materials, and, in other cases, there were some significant differences.

In addition to the tests reported in Table V, other tests were conducted with wet pure SASN and wet encapsulated materials for the purpose of determining the spark sensitivity of these materials under these conditions.

Tests were conducted with pure SASN in water, acetone and carbon tetrachloride carriers. The experiments were conducted in the same manner as the dry specimens except that a constant voltage level of 350 volts was used, testing began immediately after preparation and at incremental time intervals of 15 seconds. The results of these tests were as follows:

(1) SASN with water carrier did not detonate after 45 minutes of testing but did detonate after being air-dried overnight.

(2) SASN with acetone carrier, when placed under the electrode immediately following preparation, ignited and burned for approximately 30 seconds prior to detonation.

The burning was caused by ignition of the acetone. A separate sample was prepared, and testing began approximately 3 minutes after drying, continuing for 30.5 minutes, at which time it detonated.

(3) SASN, with a carbon tetrachloride carrier, was allowed to dry for 2 minutes before the specimen was tested. Specimen was sparked for 16 minutes before detonation occurred.

Encapsulated SASN in carbon tetrachloride was also tested, resulting in one case of a detonation after a test period of 20 minutes, and in another case using a different binder, a partial detonation occurred after 12 minutes of testing.

III. SUMMARY

From the sensitivity measurements made of an encapsulated silver acetylide-silver nitrate explosive (SASN) as compared to the sensitivity of PETN, the following observations can be made:

(1) SASN and encapsulated SASN are insensitive to the flash irradiation of a 200-watt incandescent light bult at a 1-ft distance.

(2) SASN and encapsulated SASN are insensitive to sunlight.

(3) SASN and encapsulated SASN are more impact sensitive than PETN. However, it is considered that if standard safety precautions are exercised, these explosives are relatively safe for laboratory uses.

(4) SASN, encapsulated SASN and PETN are relatively insensitive to the friction tests conducted and can be handled with relative safety in the laboratory.

(5) SASN and encapsulated SASN are considerably more sensitive to spark than PETN. Spark is considered to be the most hazardous ignition source of all tested. Therefore, when using these materials in the laboratory, extreme caution should be taken to eliminate all possible sources of spark ignition.

(6) SASN and encapsulated SASN are safest to spark sensitivity when mixed in a liquid carrier. Of the three carriers tested, water was safer than acetone and carbon tetrachloride, but all carriers were safer than in a dry condition.

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ACKNOWLEDGMENTS

The author wishes to acknowledge the support of the Ballistic Research Laboratories for the sponsorship of this program. He is also indebted to fellow workers Mr. William Mallow, for contributing to the encapsulation process of the SASN, and Mr. Marvin Rumbaugh, for conducting the experiments.

INITIATION OF EXPLOSIVES BY FRAGMENT IMPACT

JOHN J. PASZEK and VINCENT M. BOYLE
Terminal Ballistics Laboratory - W, Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland 21005

I. INTRODUCTION

The initiation of explosives by fragment impact involves in many cases a shock process with initiation taking place in a few microseconds. Yet, under certain conditions, initiation of detonation or violent reaction occurs milliseconds or even seconds after impact; indicating that mechanisms other than direct shock initiation are involved. In some circumstances it is as important to know the conditions which cause burning as it is to know the conditions that cause detonation.

To completely characterize the sensitivity of an explosive to fragment impact, it is necessary to determine the effects of charge size and confinement, fragment size, shape and material. Each variable requires a set of experimental firings so that a very large number of firings is required. Large cased charges present severe experimental problems.

Predictive models of the initiation processes would greatly reduce the required number of test firings and also reduce the need to test with large charges. The object of our investigation is to develop sufficient quantitative data to generate such models.

II. ELEMENTS OF THE EXPERIMENTAL APPROACH

To facilitate the attainment of quantitative data, the initial phase of our experimental work is being conducted with spherical fragments exclusively. Spheres, due to their symmetry,exhibit a sharply defined value for the velocity for 50% probability of initiation (V_{50}). Close control of the angle of impact, which in practice is difficult to obtain, is not required. In short, spherical fragments make it easier to detect trends in the results. When sufficient quantitative data with spherical fragments are obtained, other fragment shapes will be investigated and correlated with the sphere.

Go-no go testing for the velocity required for 50% probability of initiation of detonation (V_{50}) provides a very limited amount of information per shot. In particular, no information is obtained on the degree of reaction in the charges which do not detonate. In the experimental phase of our work we obtain, in addition to V_{50}, an indication of the degree of reaction in the non-detonating charges. An attempt to quantify this indication is underway.

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Observations of early firings led us to believe that the velocity loss of the fragment in penetrating the charge might provide quantitative data on the degree of reaction in those charges which do not detonate. For charges a few inches thick, the fragment passes through the charge and is easily recovered in celotex. At low striking velocities the fragment penetrates many inches of celotex. At striking velocities close to V_{50}, however, the penetration into the celotex approaches zero. That is, the penetration into the celotex is an inverse function of the velocity with which the fragment impacts the charge. This is in contrast with the results with inert materials where, above a certain minimum striking velocity, the velocity loss is a constant value. There is nothing surprising in this as it has been known for some time that violent chemical reaction occurs in explosives under conditions considerably less severe than those leading to detonation. These observations, however, raised the question as to whether the fragment could not be used as a self positioning probe to monitor the degree of reaction in the non-detonating charges.

The experimental arrangement is shown in Figure (1). The velocity at which the fragment strikes the charge (V_S) and the residual velocity of the fragment after passing through the charge (V_R) were measured. From these we obtained the loss in velocity of the fragment in passing through the charge (V_L). Although not shown in Figure (1), an additional velocity screen was placed on the back surface of the charge to measure the velocity through the charge of the shock wave and/or reaction wave.

III. DISCUSSION OF THE V_L vs V_S CURVE

Figure (2) is a plot of V_L vs V_S for PBX-9404 impacted by a 1.8 cm aluminum ball. These charges were 10 cm in diameter and 2.5 cm thick.

V_L increases with striking velocity, slowly at first but more rapidly as V_{50} is approached. At striking velocities very close to V_{50}, the curve has a nearly vertical slope and appears to approach V_{50} asymptotically. The maximum measured value of V_L was 90% of the striking velocity. At a slightly higher velocity, but still below detonation, the fragment was reflected back towards the gun. We have made provision for measuring the velocity of the reflected fragment and, we believe, have measured it in one instance.

The V_L vs V_S curve is remarkably smooth. Points on the curve are quite reproducible. Visual observations made after each shot indicate a good qualitative correlation between V_L and the degree of reaction in the charge. The quantity of explosive and the size of the explosive particles remaining after a shot gives an indication of the degree of reaction in the charge. A better indication is obtained from the condition of the recovered ball. The ball is recovered undistorted at low striking velocities. At higher striking velocities the ball progressively becomes more nearly hemispherical in shape. Close to V_{50} the ball collapses to an oval disk. The appearance of the ball after penetrating the explosive is entirely

different from that of a ball fired through an inert material such as wood or steel.

It is not yet clear whether V_L is a function of the intensity of the reaction in the explosive directly in front of the fragment or whether it is a function of the volume of the explosive reacting. We believe it to be the latter. Planned additional tests in which the thickness of the explosive charge will be varied will answer this.

The velocity through the charge measurements (V_C) are shown plotted against V_S in Figure (3). What is measured is the time after fragment impact for the shock wave and/or reaction wave to reach the rear surface of the charge. This provides such information as the time delay before detonation. While the V_C measurements are presently not as reproducible as the V_L measurements they are potentially more significant in terms of each of the interpretations of what is occuring within the charge. An attempt is being made to improve the reproducibility by modifying the measurement technique. In any case, there is a rough correlation between V_C and the degree of reaction in the charge.

The V_L measurement should permit a large reduction in the number of shots needed to determine V_{50}. To be fully useful, V_L must be calibrated in terms of some physical parameter such as pressure. Measurements of the pressure in the charge by means of a thin film manganin pressure gauge are underway. At this time the results are insufficient to report.

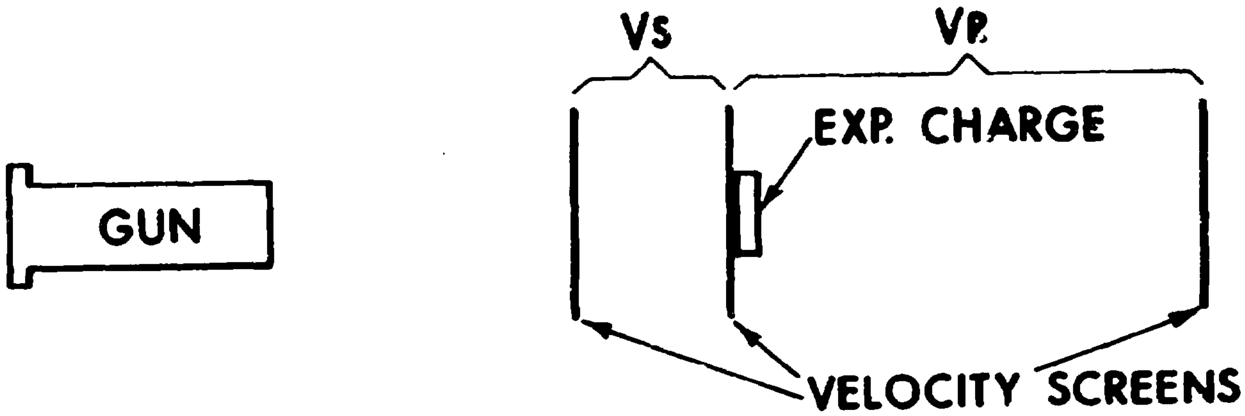
The shape of the V_L vs V_S curve at low striking velocities requires comment. Reported work by Jameson and Williams (Figure 4) and also W. V. Gerhlein of the Pitman Dunn Research Laboratories, Frankford Arsenal show that the velocity loss of a fragment penetrating an inert material is directly proportional to the thickness of the material and independent of the striking velocity (above a certain minimum velocity called the ballistic limit). For a 1.8 cm steel ball penetrating a 2.5 cm thick pine board, Gerhlein reports a constant velocity loss of 76 m/sec. for striking velocities above the ballistic limit. This provides a rough estimate of the magnitude of the velocity loss through non-reacting PBX-9404. Below the ballistic limit V_L actually increases with decreasing V_S. This is clearly shown in the curve of Jameson and Williams for penetration of steel plate. At very low striking velocities a correction for this effect must be applied to the V_L curve for PBX-9404.

IV. RESULTS AND CONCLUSIONS

Early results include a value for V_{50} for two explosives. For Composition B, in a charge 10 cm in diameter and 2.5 cm thick, impacted by a 1.8 cm steel ball, the value for V_{50} is 1750 m/sec. For PBX-9404, in a charge 10 cm in diameter and 2.5 cm thick impacted by a 1.8 cm aluminum ball, the value for V_{50} is 1250 m/sec.

The measurement of V_L and V_C facilitates rapid determination of V_{50} since an indication of closeness to detonation is provided for each shot. If these measurements can be made to yield quantitative data the results will be used to build predictive models of the initiation process which is the ultimate goal of these investigations.

SCHEMATIC OF VELOCITY MEASUREMENTS

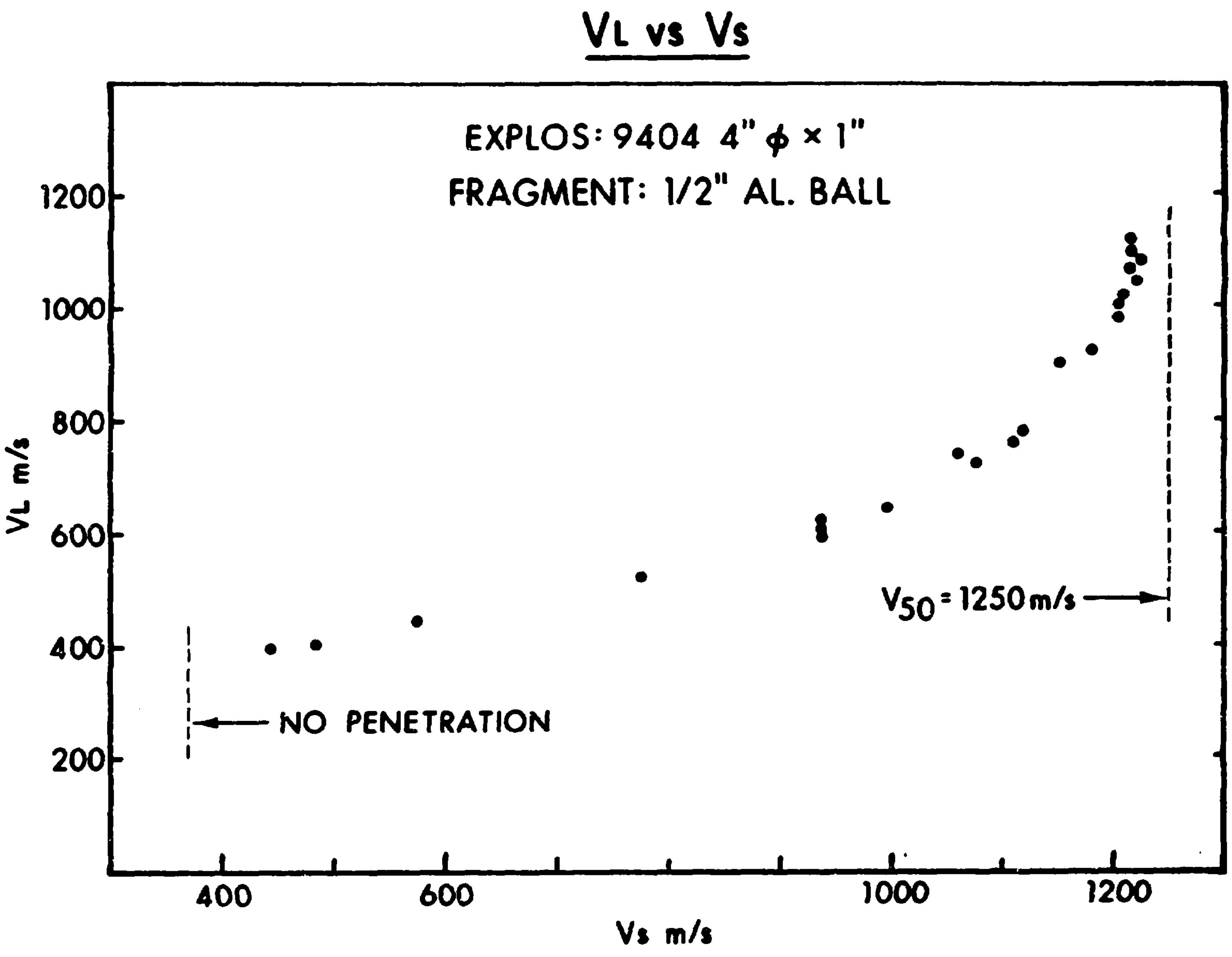


V_S = FRAGMENT STRIKING VELOCITY

V_R = RESIDUAL VELOCITY OF FRAGMENT AFTER PENETRATING CHARGE

$V_L = V_S - V_R$, FRAGMENT VELOCITY LOSS THRU CHARGE

Figure 1.



VL vs Vs
EXPLOS: 9404 4" ϕ × 1"
FRAGMENT: 1/2" AL. BALL
1200
1000
800
600
400
200
VL m/s
400
600
1000
1200
Vs m/s
V50 = 1250 m/s
NO PENETRATION

Figure 2.

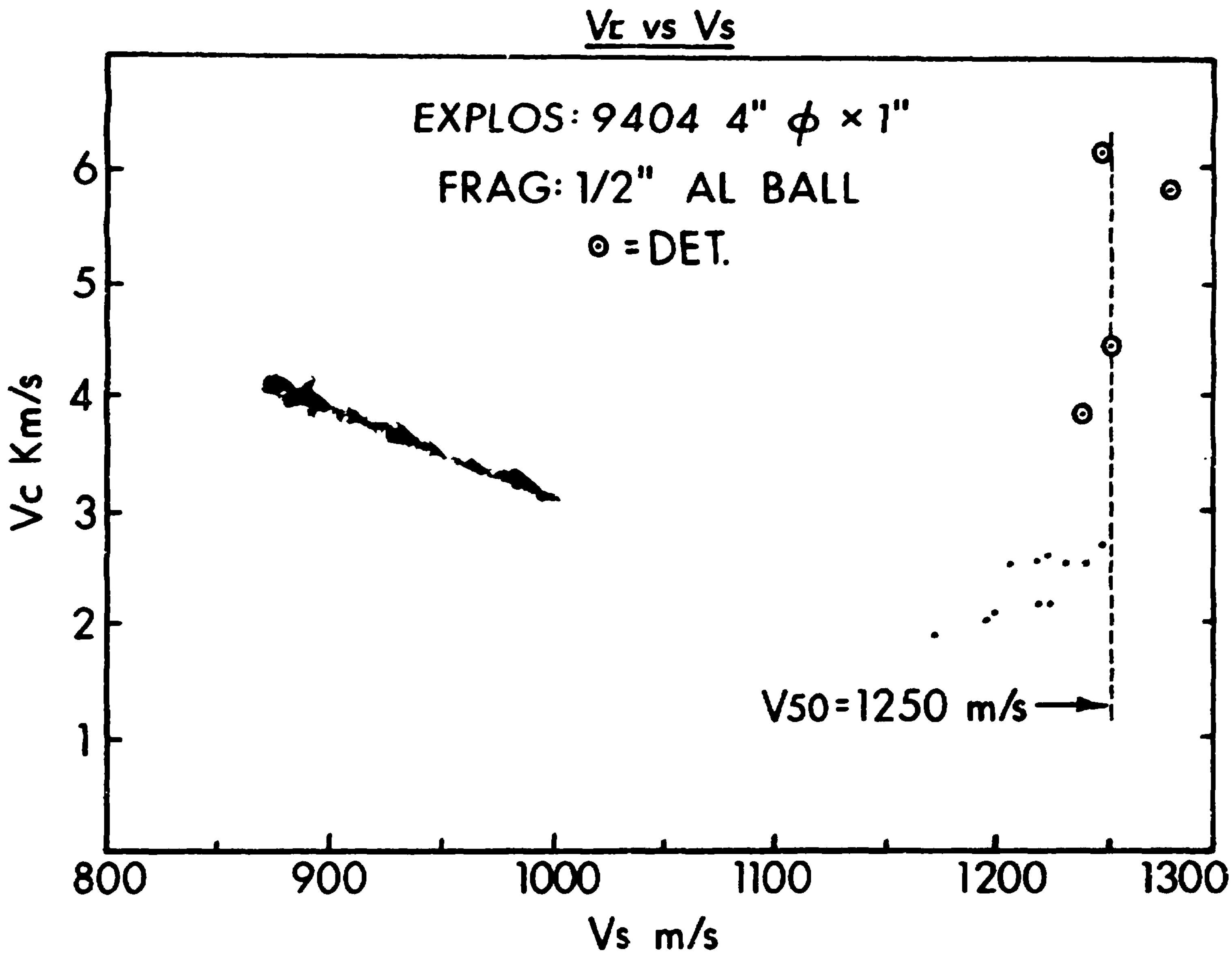

Vc vs Vs
EXPLOS: 9404 4" φ × 1"
FRAG: 1/2" AL BALL
⊙ = DET.
V50 = 1250 m/s
Vc Km/s
Vs m/s
6
5
4
3
2
1
800
900
1000
1100
1200
1300

Figure 3.

30 CAL 6.6 GRAM STEEL CYLINDER vs 6.4 mm THICK STEEL PLATE

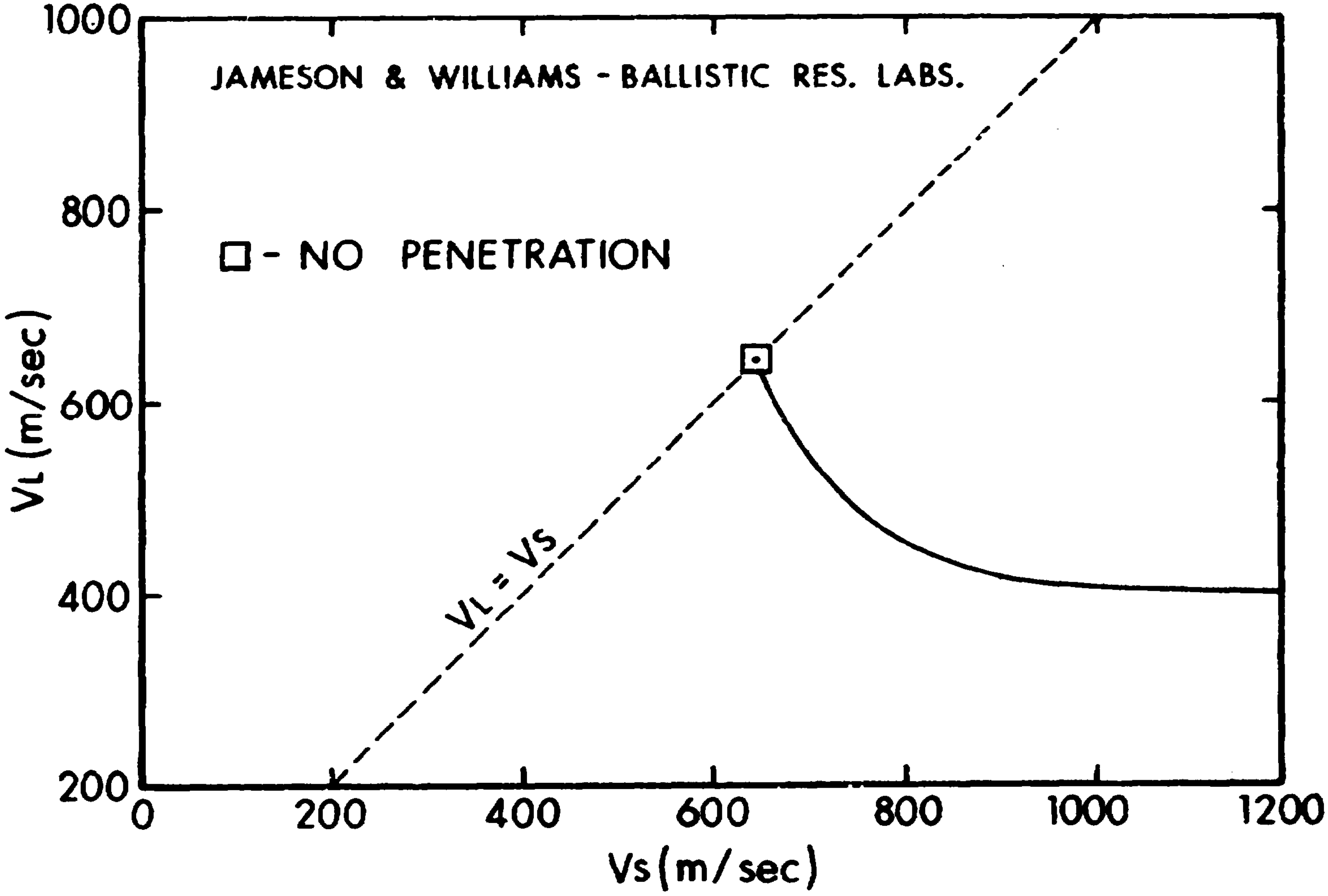


Figure 4.

The Navy's Development of Explosive Safety Procedures for Loading and Dunnaging of Ammunition Cargo Aboard Ships

Douglas M. Osborn
NAD Earle, Naval Weapons Handling Laboratory
Colts Neck, New Jersey 07722

I would like to trace the development of the Navy's procedures and practices for the safe loading and stowing of military explosives in cargo ships, the merchant type vessels (which include the MSC nucleus fleet and the larger population of vessels under charter) and the Navy ammunition ships. For purposes of this discussion, I have used a single tragic event - the sinking of the SS BADGFR STATE in the first days of 1970 - as the dividing line between eras in the Navy's ammunition shiploading history over the past 30 years. The BADGER STATE incident was unique for it was the first time that a ship was lost as the result of ammunition cargo becoming loose in the holds and I will detail this unfortunate event later.

Although it was not without lessons (some of which were forgotten or not learned, as we will see), I will only briefly review the pre-BADGER STATE era of shiploading. During World War II and up thru the early 1960's, ammunition was man-handled and stowed aboard ship as loose rounds or containers. The holds of Navy ammunition ships and merchant vessels were essentially the same in configuration, and ammunition was stowed in cordwood fashion in much the same manner as the rows and stacks of cartridge tanks seen at an ammunition depot or dump today. There was little formal detailed documentation pertaining to shiploading practices and techniques until early 1946 when OP 1658 "Issue Loading Fleet Ammunition Ships" was prepared and issued, and gathered together the best of the ammunition cargo loading practices and procedures learned during World War II. The preparation of another such document did not again occur for a period of 24 years - and was triggered then only because of the tragic event in the Northwest Pacific. OP 1658 remained unchanged and in effect until 1970. From a practical standpoint, it was a useful document until the early to middle 1960's when palletization of ammunition, which required new techniques for both handling and stowage, became accepted for shipboard stowage. In addition to this lonely OP, one Navy training film was also prepared relating to the shiploading process and had approximately the same life span as its printed running mate. The void in formal publications, training aids and programs, and technical guidance thus spanned a period of 6-7 years during which Navy shiploading activities essentially pioneered their own methods, which were based on the general criteria of Coast Guard Publication CG 108 (CFR Title 46 part 146) and in some instances, documented these practices on local basis. Fortunately,

the Navy, in this period, was blessed with a depth of experience and expertise at the various CONUS outloading terminals and ships went to sea safely loaded. In fact, there were no serious explosive incidents from the start of WW II until BADGER STATE traceable to shifting cargo aboard ship. There were, however, two major catestrophes which were the probable result of improper or accidental handling during loading operations. These incidents were the explosion at Port Chicago (Now WPNSTA Concord) which destroyed the pier complex and the disintergration of a Navy ammunition ship, USS MT. BAKER, in a Pacific island harbor.

The following is the message sent by the Master of the BADGER STATE immediately after his rescue. "We tried to rescue the cargo using all ships matresses, hatch boards, spare life jackets, chairs, linen, stewards stores, frozen meat, mooring lines, beds, fire hoses--anything we could use to try to stop them from rolling around. Landed pontoons on top of everything to try to stop them--at this time we came about in an attempt to head for Midway and some of the bombs exploded in Number 5 hatch and it was on fire at that time. The abandom ship signal was immediately sounded". The items he tried to stop rolling around were 2,000 pound bombs. For those of you not familiar with the incident, the SS BADGER STATE, under MSC charter, was loaded at NAD Bangor (now the Bangor Annex of NTS Keyport) in early December 1969 with a cargo of Air Force bombs and rockets. During the voyage, the ship was subjected to a continuous series of violent storms which resulted in the vessel rolling up to 53°. Engineering problems left her dead in the water for several hours at a time. The ammunition cargo broke loose and began shifting in all 5 holds and despite the heroic efforts of the crew to shore up the ammunition, one or more 2,000 lb. bombs exploded low order in No. 5 hold, blowing a 12 ft. hole in the side of the ship and starting fires in the debris in the hold. 25 of the 39 crewmen lost their lives while abandoning the ship which, paradoxically, did not explode and remained afloat for 5 days before sinking. Besides this tragedy, the winter of 1969-70 produced other similar incidents at sea - all serious but fortunately with happier endings. Navy ships had their troubles in heavy seas also with cargo breaking loose in holds. These incidents were directly attributable to improper or inadequate dunnaging of the ammunition. As a result, the Naval Weapons Handling Laboratory, NAD Earle, because of its technical background in blocking and bracing methods used in land transportation, and its knowledge of cargo handling and stowage aboard AE, AOE and AOR type ships, was directed by NAVORDSYSCOM in February 1970 to review the shiploading practices at the Navy's 3 primary transshipment stations (WPNSTA Concord, NAD Earle, NAD Bangor) and establish what actions or improvements were necessary to prevent or reduce the possibility of such disasters or near-disasters again occurring at sea.

This review determined the following findings. There was little interaction between the Naval transshipment stations and the NAVORD Headquarters since nearly 80 percent of the ammunition cargo being loaded was Army/Air Force. For the most part, problems in shiploading were resolved on a local level in concert with MTMTS, MSC (then MSTS) and Coast Guard organizations. The stations had tranditionally performed well in this mission with experienced, well qualified personnel. Additionally, there was a feeling that shipboard dunnaging is an art and therefore not particularly given to sophisticated management and technical direction. However, the results of activities performing with minimum central headquarters management and little or no technical guidance resulted in the following: No formal guidance, standardization and documentation in dunnaging designs, practices, and procedures. Each activity had created its own standards, as previously noted, and there were different practices from station to station. The dunnaging of merchant ships was found to be, (and still is in many respects) an art, not an engineered science, almost totally dependent on the talent and experience of the individual blocker and bracer. The dunnaging designs and methods were done on a trial and error method. Any feedback on the success or failure of these designs was obtained only on damaged cargo reports or in discussion with the ship's crew months later when it returned for another loadout. There was no formal feedback system so essential in determining the adequacy of a design.

I might digress here for a moment to give the uninitiated a short guided tour of just what I mean by dunnaging. In breakbulk type merchant vessels, the 5,000-8,000 tons of cargo is restrained totally by the use of wood structures. A single ship requires 100,000 - 200,000 board feet of lumber and a ½ ton of nails - the equivalent of 14 - $50,000 houses. On Navy ammunition ships, metal dunnage systems have been installed employing stanchions which are placed in a track system. Wood is required only as ocassional filler between loads and stanchions. While less complex and time consuming than the merchant ship dunnage methods, these metal restraint systems none the less must be used properly and carefully.

Another finding was that with the exception of WPNSTA Concord, which uses the Coast Guard as their Quality Assurance Inspector, the inspection and certification of dunnage and stowage operations was being accomplished by the same personnel who supervised or did the work, and by the master or mate of the ship who might not be knowledgeable in the shiploading of explosives. It is apparent that a truly objective inspection by an individual of his own work is difficult if not humanly impossible. There was, in addition, no standardization in inspection procedures. With the exception of winch and fork trucks,

formal training, like formal documentation, was also found to be lacking during this review. Most of the instruction was of an on-the-job nature with personnel progressing from rudimentary jobs thru apprentice blocker and bracers or riggers. No practical training aids or de- es were available.

And finally, the review revealed problems in standardization of handling equipment used at dockside and in the unit loads. Navy handling equipment was frequently incompatible with Army/Air Force unit loads and containers. The design of some Army/Air Force unit loads and containers did not consider the shiploading and stowage environment - particularly skidded loads of the projectiles which created problems in handling and stowage.

What came out of this study and its findings? Essentially, an effective on-going program with positive corrective actions completed and continuing in nearly all areas of concern.

A Technical Management Office (ORD-0524) has been established in NAVORDSYSCOM Headquarters and the Naval Weapons Handling Laboratory, NAD Earle is designated as the Technical Directing Activity to provide technical guidance and standardization in shiploading.

NAVORD OP 3221 Shiploading and Dunnaging of Military Explosives Cargo Aboard Merchant Type Ships, the document superseding OP 1658, was issued in late 1970 and contains, in detail, the best of the Navy's merchant shiploading practices. It also replaces the local standards and expands upon the general criteria in CG 108. This OP has been made mandatory by the Chief of Naval Operations for use by all Navy outloading activities, and has been changed twice since its issue. Of the 1,000 copies pointed, only 68 now are in stock so its wide distribution is obvious.

NAVORD OP 3206 1st R Handling and Stowage of Naval Ordnance aboard Ammunition Ships, sued in 1971, has an entire chapter dealing with the use of the metal dunnage and wire net shoring systems. The remainder of this three volume OP details handling equipment and operations aboard the various types of Navy ammo ships
This OP has been updated once since its issue as part of the effort to insure that documentation in this field never again becomes obsolete or useless. Hopefully, we have learned that lesson once and for all!

Inspection of shiploading at Navy activities has now become the responsibility of third party - the Quality Assurance Department of all stations except at WPNSTA Concord where the Coast Guard continues in this role. Inspection procedures and forms have been standardized, as has a feedback system for reporting on the adequacy of the stowage.

Three thiry minute training films "Shipboard Loading and Stowage of Ammunition Cargo", MN-10921, A, B, C, have been produced covering both the principles and the detailed procedures for merchant and Navy shiploading. A full scale training facility is now located at NAD Earle. This convered barge is used for dunnage training of all kinds, as well as experimental work in developing new stowage techniques. A training program for shore station personnel has been implemented under the NAVORD Safety School with courses given twice a year in CONUS. This training course has also gone on the road recently, being given by NWHL and Safety School personnel in Japan and in the Philippines last summer. It will be offered to NATO and Navy activities in the European and Mediterranean in January 1974, and in Guam and Hawaii in November 1973. The overseas training is the result of problems coming forth during the roll-back of retrograde shipments from SEA and Europe in the last 18 months. These shipments arrived in such hazardous conditions, both in packaging and dunnaging, as to create major safety problems at the receiving ports. The DDESB is well aware of the furor raised over these shipments which came from both Army and Navy ports.

Major progress has also been made in cooperative effort with the Army and Air Force to improve and standardize ammunition shipping configurations.

Concurrent with the Navy corrective effort, the Coast Guard and National Transportation Safety Board findings and recommendations concerning the BADGER STATE incident were published. The NTSB recommended that the Coast Guard, with the Navy and Army, develop stowage criteria to meet specific vessel response to dynamic environmented conditions and using these criteria, conduct an engineering study to develop dunnage design requirements to safely restrain cargo in heavy seas. An AD HOC committee chaired by the CG, is now working on a study to establish the forces on cargo in a ship's hold. This effort, which will be verified by at-sea tests, should be complete in the next six months and from there the design study will go forth.

And where do we go from here? A joint Army-Navy Technical Manual is under preparation so that world-wide coverage can be achieved in break-bulk shiploading documentation. The OP-TM is expected to be issued within the next 12 months. In conjunction with the joint publication, a world-wide training program must also be instituted.

And, as covered in presentations during the last DDESB Seminar, effort is commencing in the application of Containerization and LASH - the new water transportation systems for the 1980's - for shipment of ammunition cargo.

While the Navy has taken giant steps toward improving shiploading safety over the past three years, we have been, realistically, playing "catch-up ball". There is still much to be accomplished in the present state-of-the-art as well as preparation for the future in shiploading of military explosives.

MODERN FACILITIES FOR THE TRANSPORTATION AND HANDLING OF EXPLOSIVES BY MOTOR COMMON CARRIER

Bill Sanders
Tri-State Motor Transit Co.
Joplin, Mo.

On behalf of Tri-State Motor Transit Co. management I wish to express our deep appreciation for this opportunity to bring you this presentation on the safety practices, procedures, and equipment, including the modern facilities, used by our company for the transportation and handling of explosives and other hazardous materials as a motor common carrier.

I am going to give you very briefly an overview of our facilities and equipment with this slide presentation.

Tri-State Motor Transit Co. is headquartered in Joplin, Missouri. We are an irregular route, specialized motor carrier and we are one of the nation's leading motor carriers in the handling of dangerous items such as explosives and radioactive materials operating throughout the United States and to and from parts of Canada.

For truckload shipments we possess authority to serve all forty-eight (48) states but not between all points. For less than truckload shipments, we possess the authority to serve all forty-eight (48) states for the movement of security classified and sensitive shipments, between all points, which can encompass explosives and radioactive commodities.

In addition, we also transport other specific items of heavy weight, large size, and/or unusual configurations which require handling or rigging. Indeed the company prides itself on its readiness to tailor its service and equipment to its shipper needs, consistent with an adherence to the highest standards of safety and responsibility. It is within this context and, particularly for the handling and movement of explosives, that our company operates driver training school in many parts of the country to attract, train, and retain drivers who can meet the company's stringent performance requirements.

To supplement our ability of providing continuous contact with our shippers and company personnel for the exchange of mutual information and tracing of hazardous shipments en route to ultimate destination, we maintain a nationwide inbound telephone WATS service. This service is available to all our customers, twenty-four (24) a day, seven days a week at no cost to the shipper. It provides direct contact with all operating departments. It also enables our drivers to maintain constant contact with the company. The U.S. is divided into three geographical areas with a specific line for each delineated area.

To further facilitate the handling and movement of dangerous commodities, we have established a nationwide network of terminal facilities. To accomplish this capability, we have acquired hundreds of acres of land in non-congested areas which are security fenced and guarded. We have constructed revetted holding areas in a number of these locations with the primary purpose of holding, servicing, and scheduling loads of hazardous materials.

In this manner we can also provide back-up service to port areas which are congested or exceed the allowable maximum explosive content. This capability is also available to ConUS DoD facilities, who likewise cannot receive explosive shipments at a particular time due to extenuating circumstances, i.e., exceeding allowable maximum explosive content or lack of storage/holding areas. Our company provides the only transcontinental network of such facilities in existence to date.

A revetted terminal, such as our facility at Joplin, Missouri, will have:

1. Guard House
2. General Office
3. Computer Equipment
4. Operations Department
5. Safety Department
6. Drivers' Training Classroom
   a. Safety receives first considerations at Tri-State.
   b. We practice selective hiring and perform road tests under various conditions insuring the hiring of only the most competent personnel, who in addition to the road testing must have passing grades in the training schools.
7. Driver Lounge
   a. Restroom facilities
   b. Laundry room
   c. Showers
8. Maintenance Shop
9. Inspection Lane
10. Revetted Area
11. Signs and warnings on way to revetted area.

It is our contention that the care and effort we have made to provide our drivers with the facilities as outlined for the drivers' lounge enables our company to insure that our drivers are well rested, comfortable, and capable of providing the type of service and alertness that is necessary in the handling of hazardous materials by driver personnel.

The hazardous materials definitions which our drivers are schooled in and are concerned with are:

1. Explosives - Class A. Nine types of Class A - detonating or otherwise of maximum hazard.
2. Class B - In general, function by rapid combustion rather than detonation and include some explosive devices.
3. Class C - No placards required. Certain types of manufactured articles containing A or B, or both as components, but in restricted quantities.
4. Code of Federal Regulations, Title 49.

The types of equipment used for ammunition loads are:

1. Closed vans
2. Flatbeds
3. Drop-decks
4. Self loaders
5. Droms (used for small quantities of explosives)

The safety precautions which we foster and practice as an integral part of our program include the installation of two fire extinguishers per truck. Each one is two times the size required by law.

Upon leaving the terminal, the equipment receives a last and final check at the guardhouse gate by safety personnel. This check insures that the necessary paperwork for the shipment is proper and complete, the equipment is completely serviceable and no defects are visible, and that the driver is well rested and ready for his dispatch. A tire and equipment inspection is made by the driver on the vehicle every two hours or fifty miles of travel to prevent tire fires. Smoking is absolutely forbidden on any loaded vehicle transporting explosives or hazardous materials, also during loading or unloading.

All explosives and hazardous materials are properly placarded in accordance with DOT and DOD regulations. For explosives and hazardous materials transported on two lane highways the maximum speed is 50 miles per hour. On four lane, divided highways, the maximum speed will be 55 miles per hour. Company policy requires a distance of not less than one-fourth of a mile between each moving vehicle.

A constant safety check is made by our safety patrol on a round the clock basis, coast to coast, to observe and assist our drivers. Our safety department has twenty five personnel assigned, of which there are seven road safety supervisors who patrol the highways. The road safety supervisors will be responsible for checking the drivers' safety habits and skills, equipment inspections, drivers' daily logs, placarding of

hazardous materials, tie-down and tarping of cargo, attendance of explosives laden vehicles, and other such responsibilities of the drivers. These safety checks will be made at all terminals, or at any location where the safety supervisor observes a Tri-State Motor Transit Co. piece of equipment.

The road safety supervisor will complete an observation report on each unit which he inspects or observes. This report will contain information with regard to the drivers' safety habits, daily log, medical examination certificate, certificate of written examination, safety equipment, and tractor-trailer conditions.

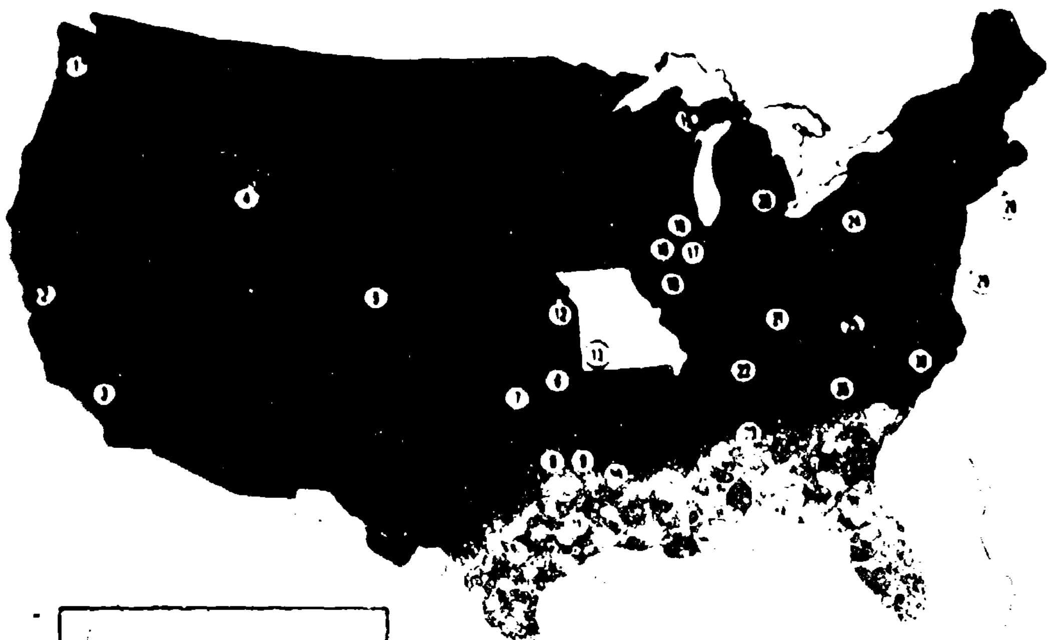
If the road safety supervisor's inspection reveals any major defects which may jeopardize the safe operation of the equipment, the road safety supervisor will require that the deficiencies be corrected immediately. Any minor deficiencies will be corrected at the first feasible location.

In this short period of time I have attempted to make you aware of and assure you that we at Tri-State Motor Transit Co. are fully cognizant of our responsibilities in the handling and movement of your hazardous materials. I have also attempted to acquaint you with the actions we have taken as a motor common carrier with our personnel, equipment, practices, and facilities to insure the safe transportation of your commodities. In this endeavor we have expended great effort, man hours, and money to assure the finest service available to you, our customer.

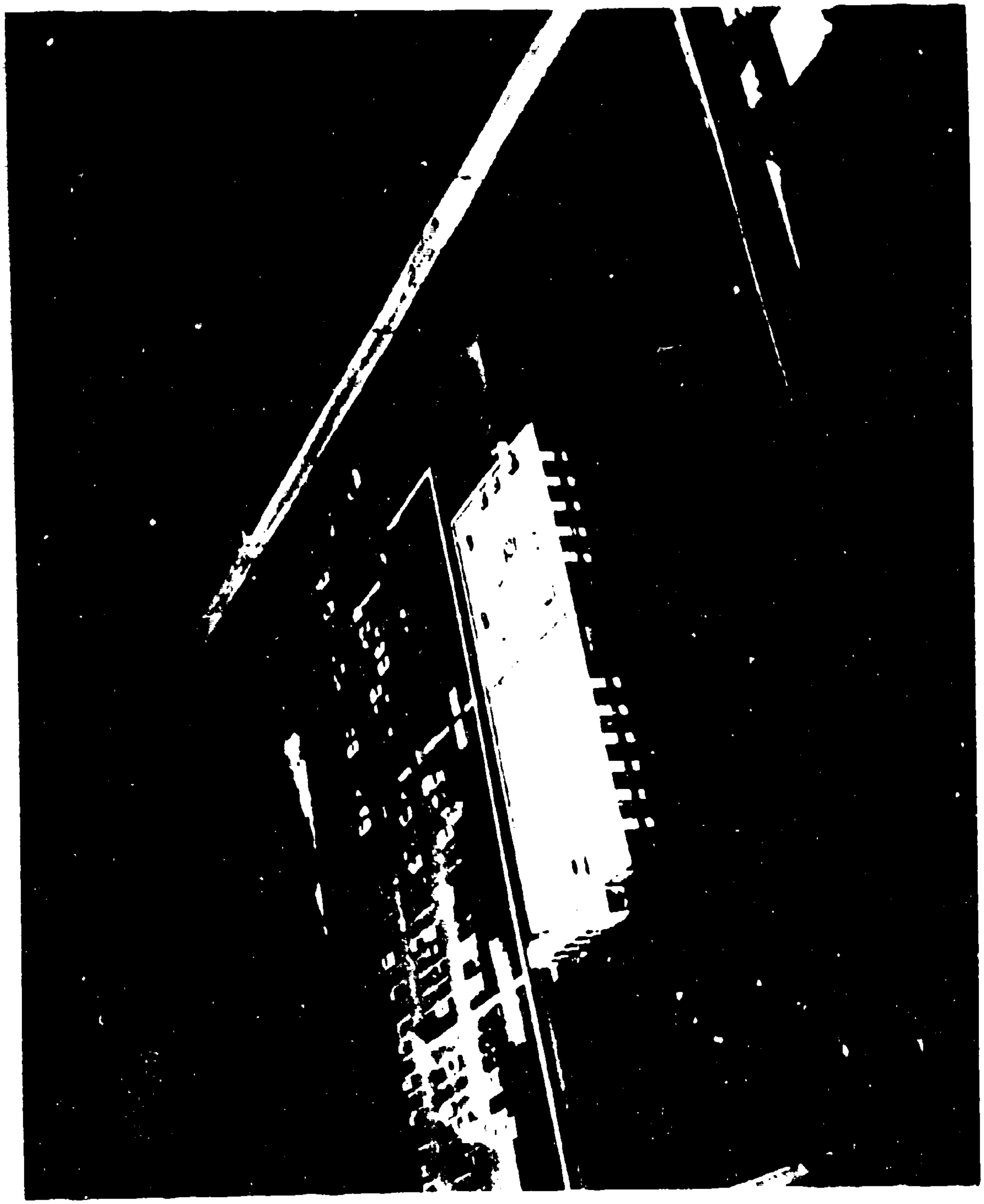
I will close by saying, safety is our foremost consideration.

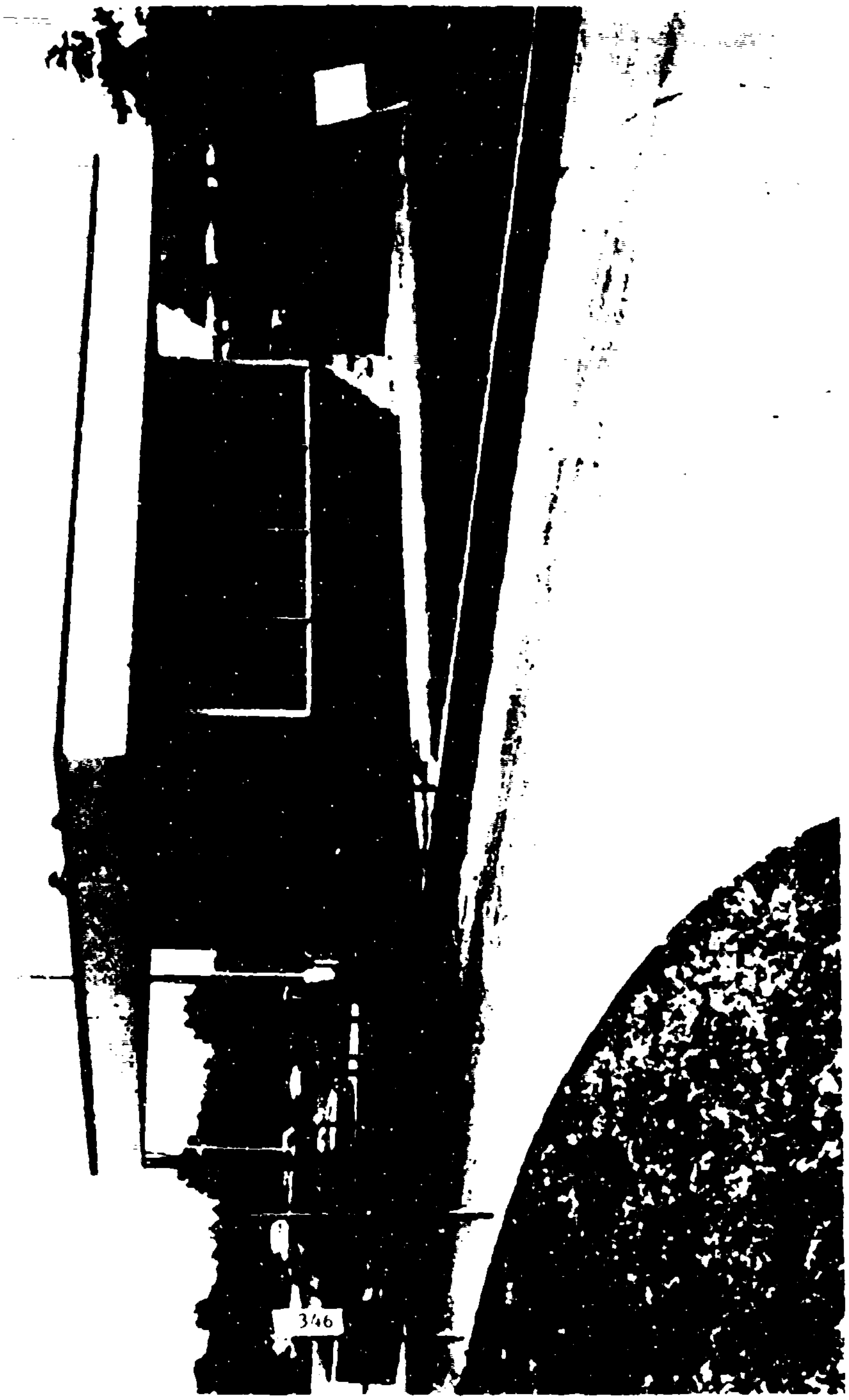
TRI-STATE MOTOR TRANSIT CO.

EXPLOSIVES Nuclear Aerospace Heavy Hauling Pipe Line Other Specific Commodities



COMMUNICATIONS and TERMINAL LOCATIONS

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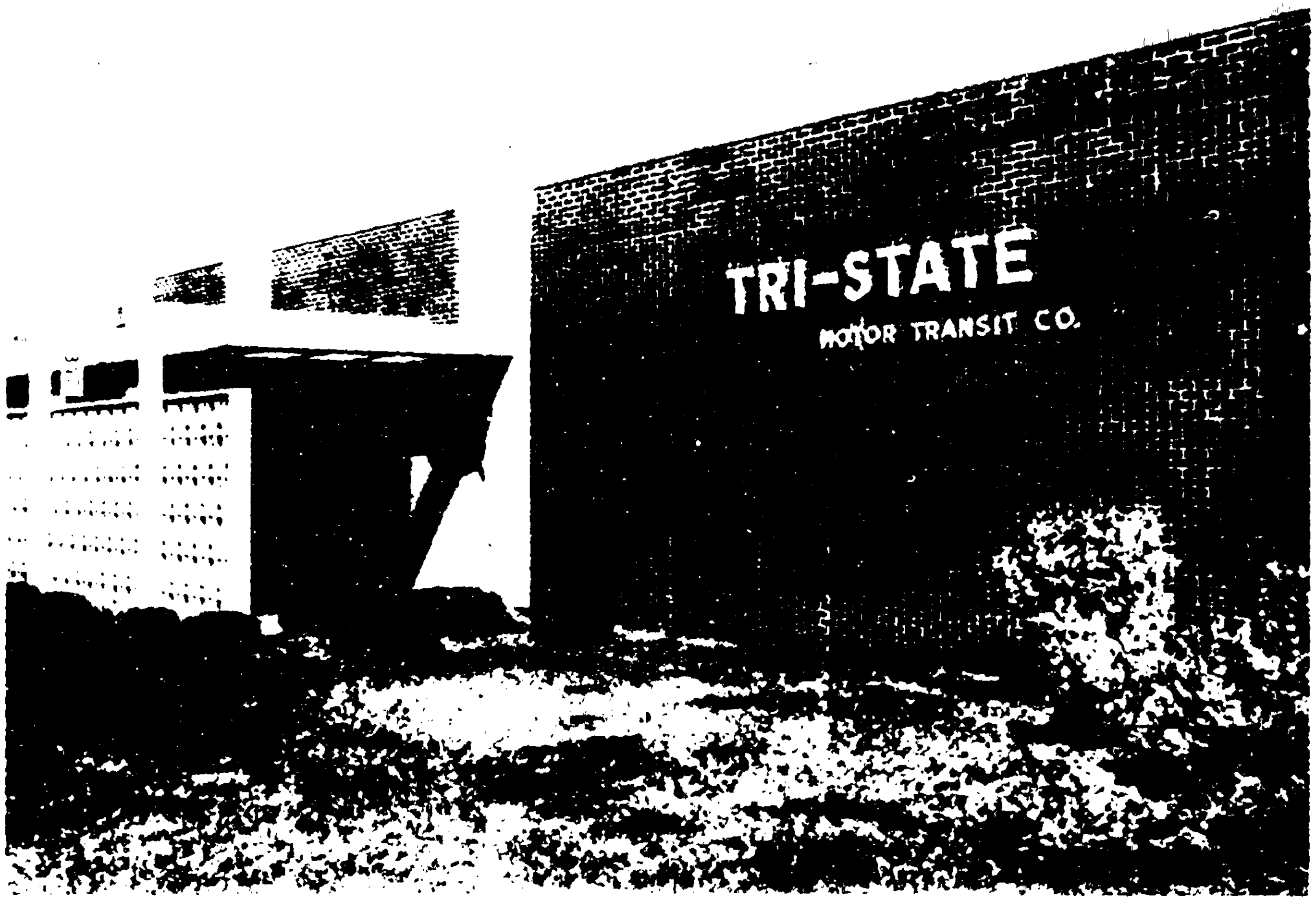
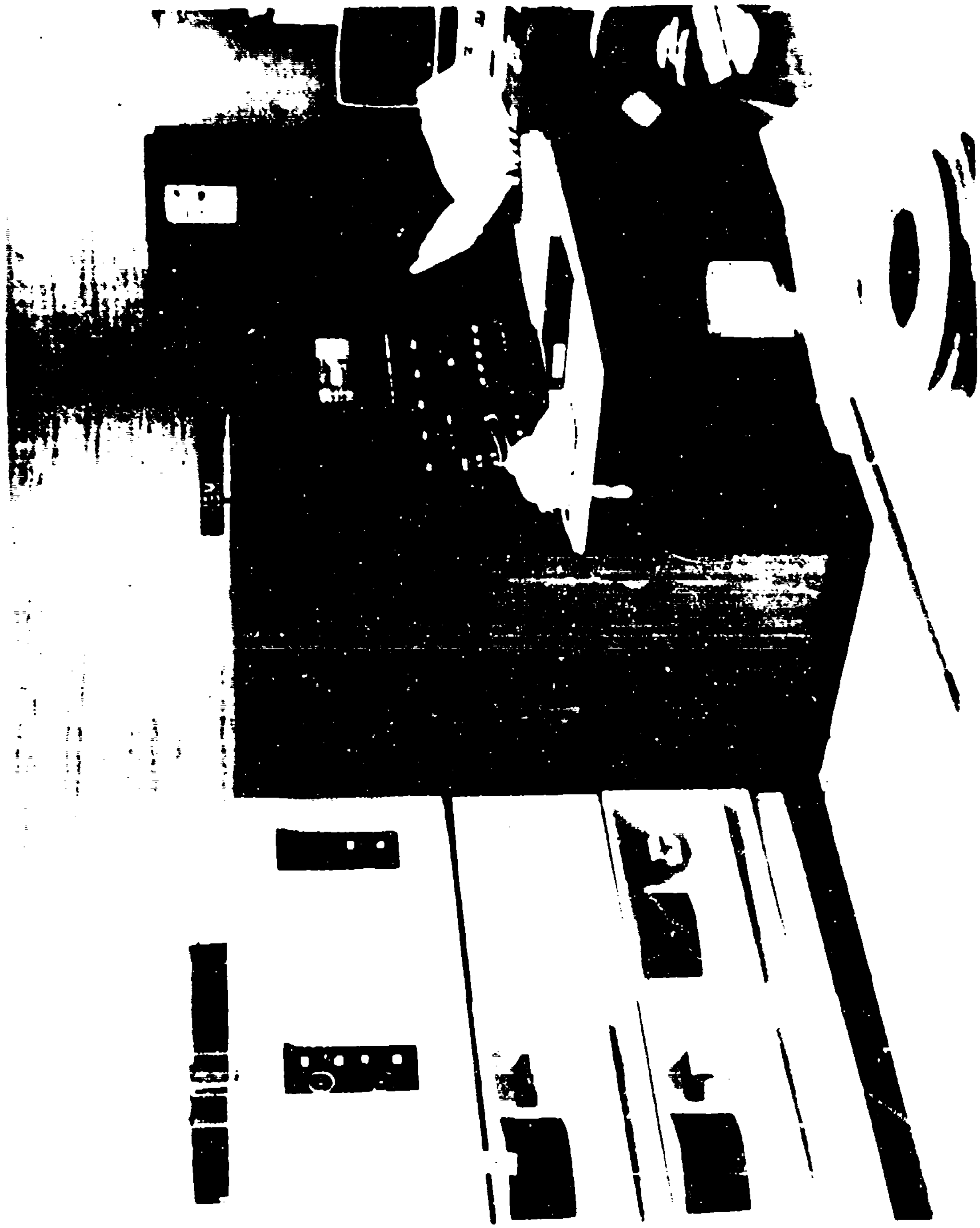
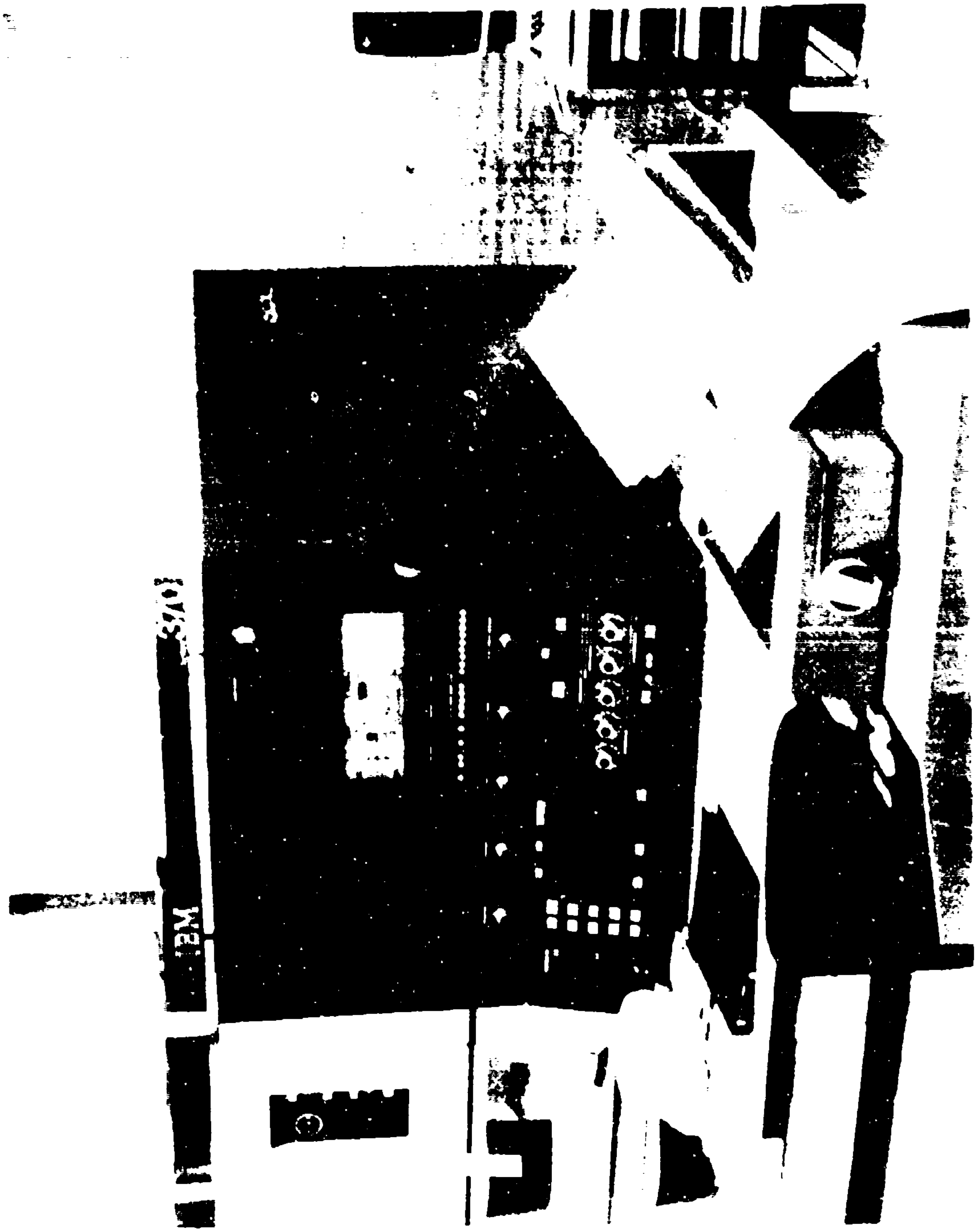

TRI-STATE
MOTOR TRANSIT CO.





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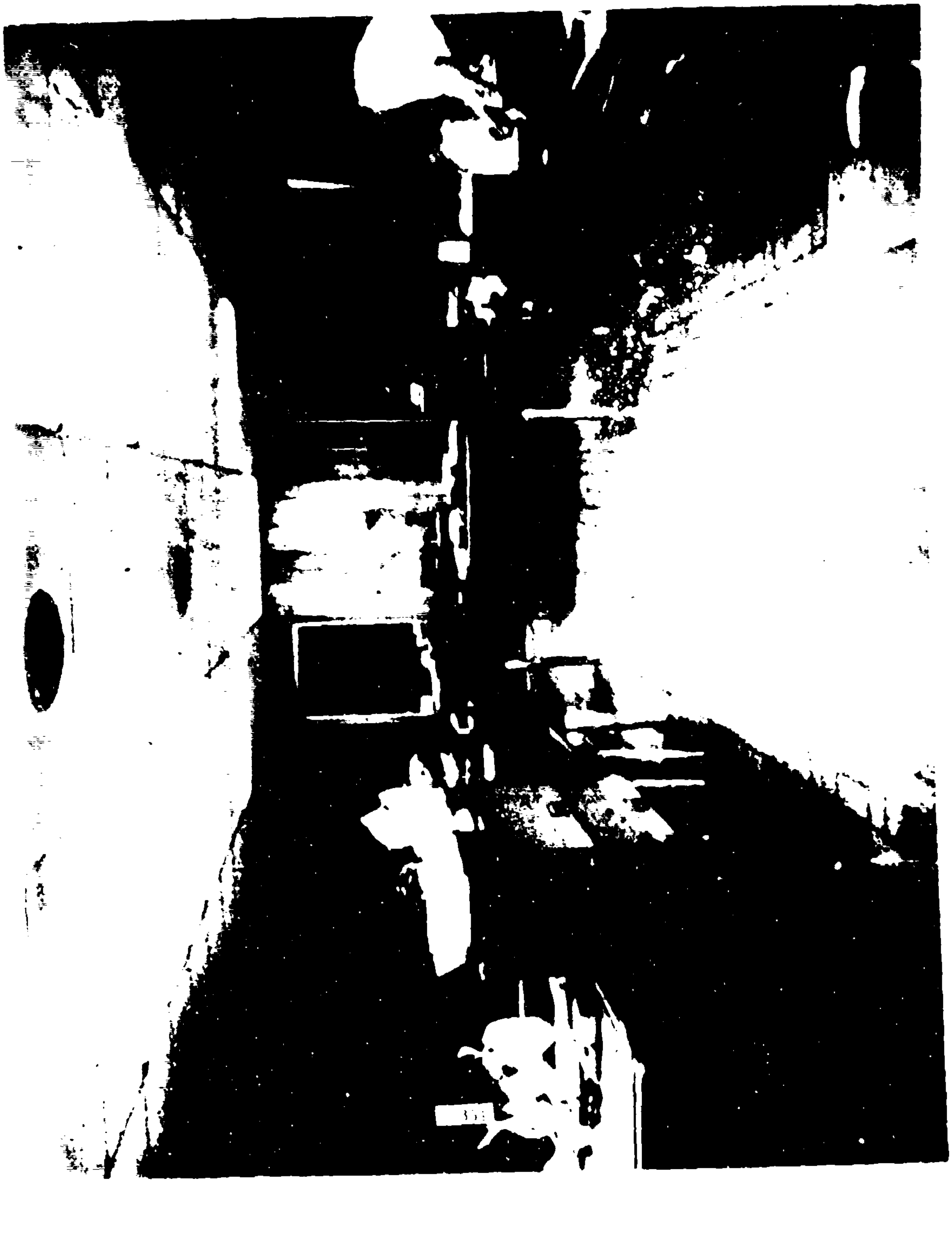

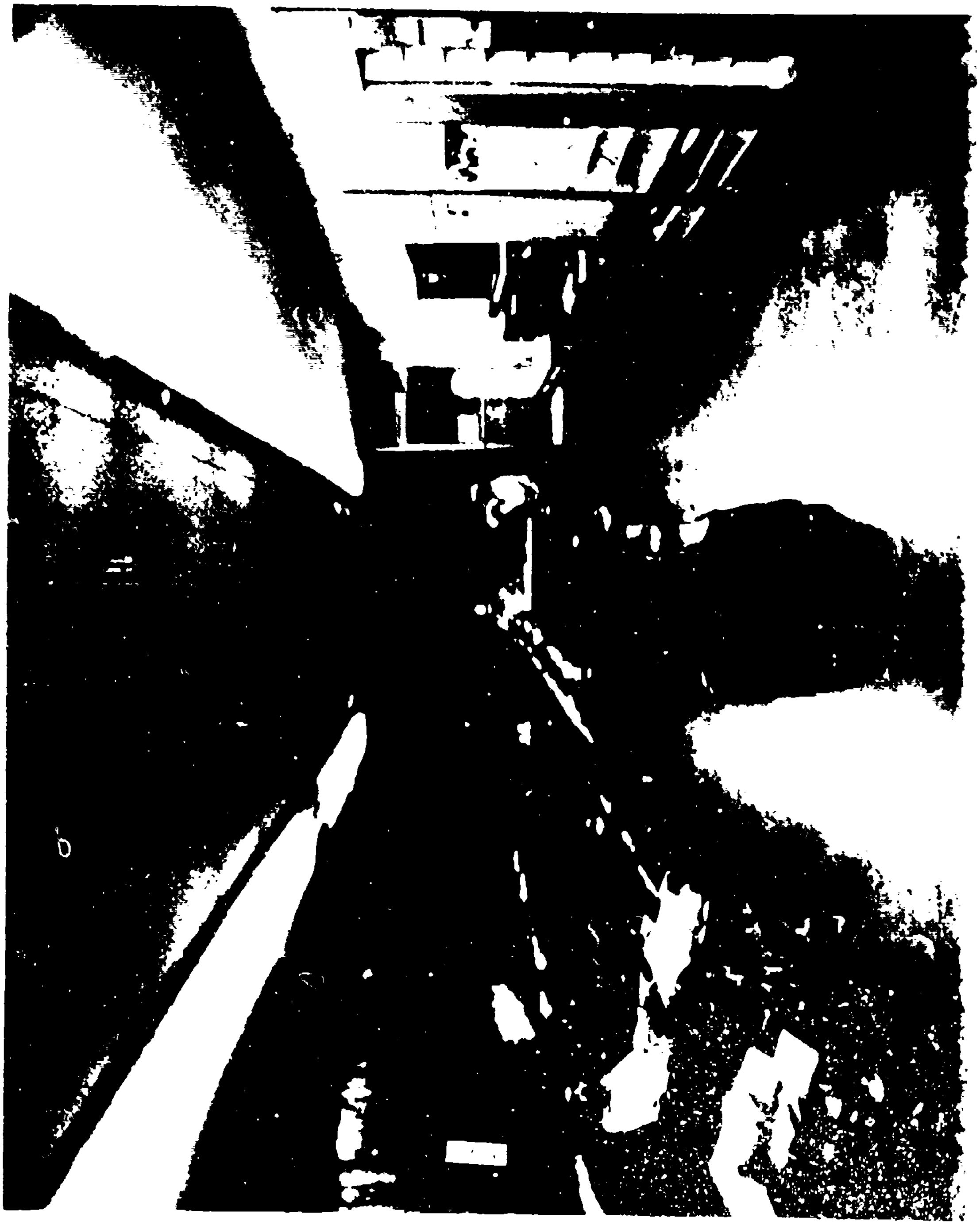

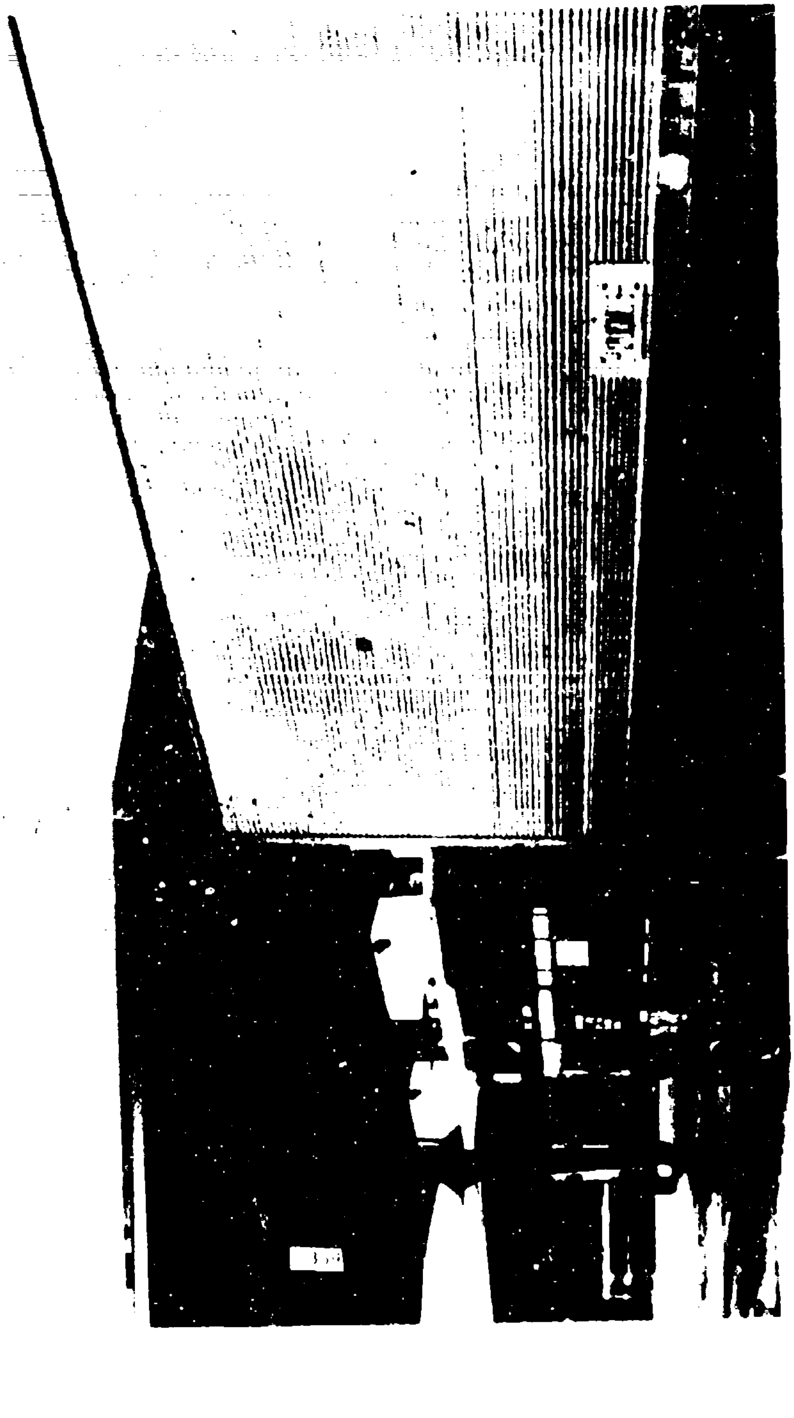


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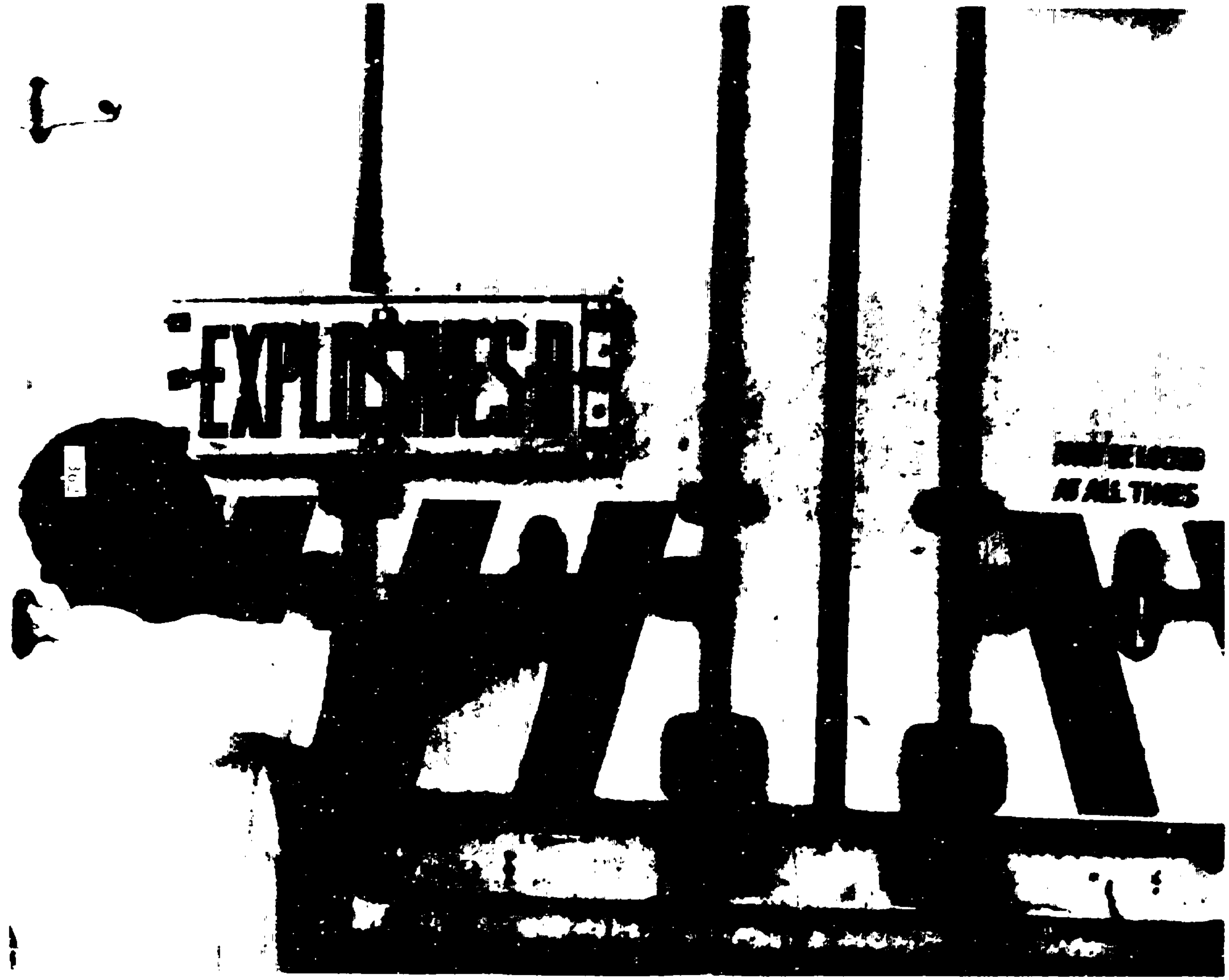
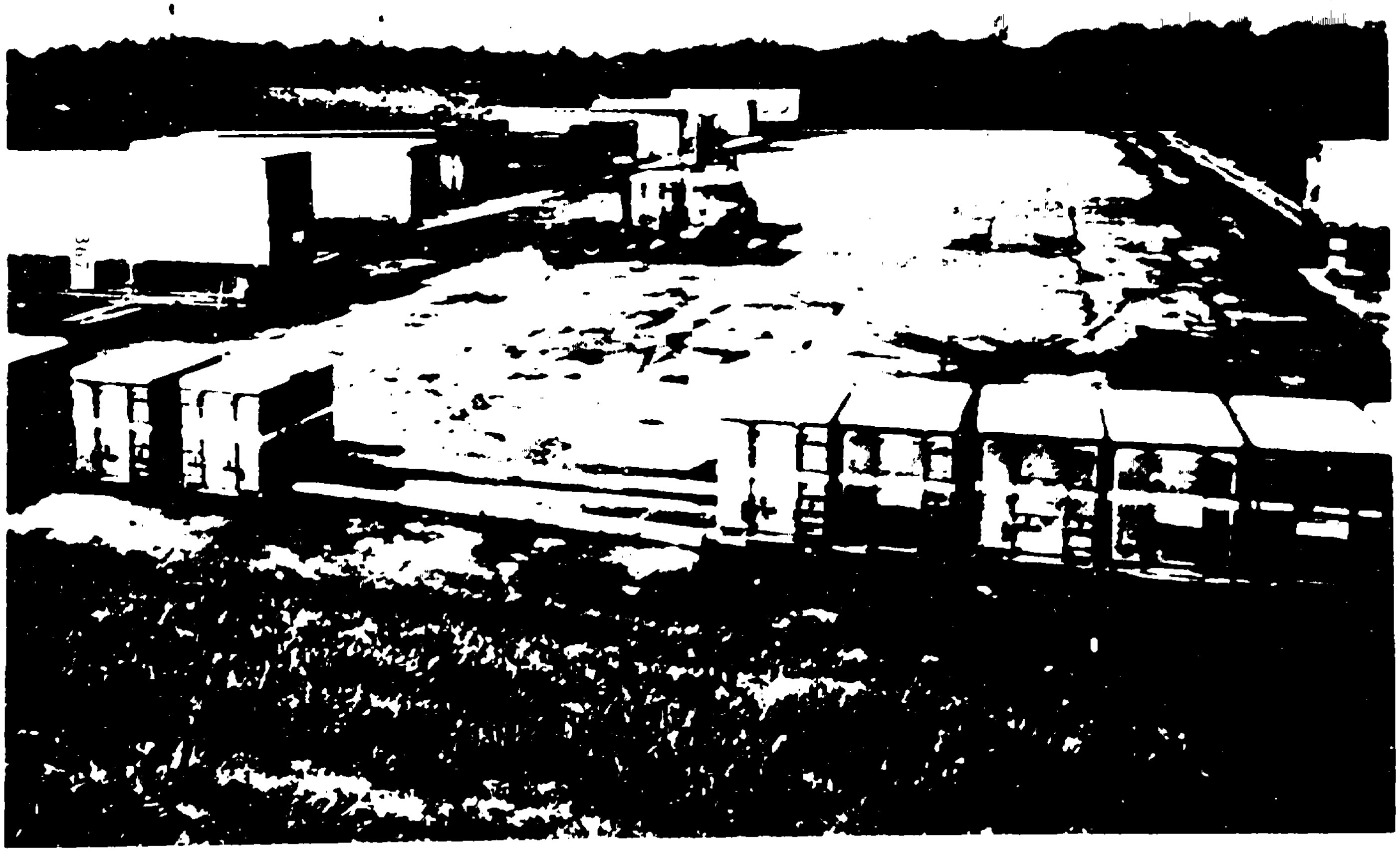

EXPLOSIVES
AT ALL TIMES


STOP
PLEASE LEAVE LIGHTER MATCHES
AND CIGARETTES IN THIS BOX
NO SMOKING
PAST THIS POINT
EXPLOSIVES
WARNING
SPEED LIMIT
5
MILES PER HOUR


STOP
NO SMOKING
EXPLOSIVES
WARNING
SPEED LIMIT
5
MILES PER HOUR



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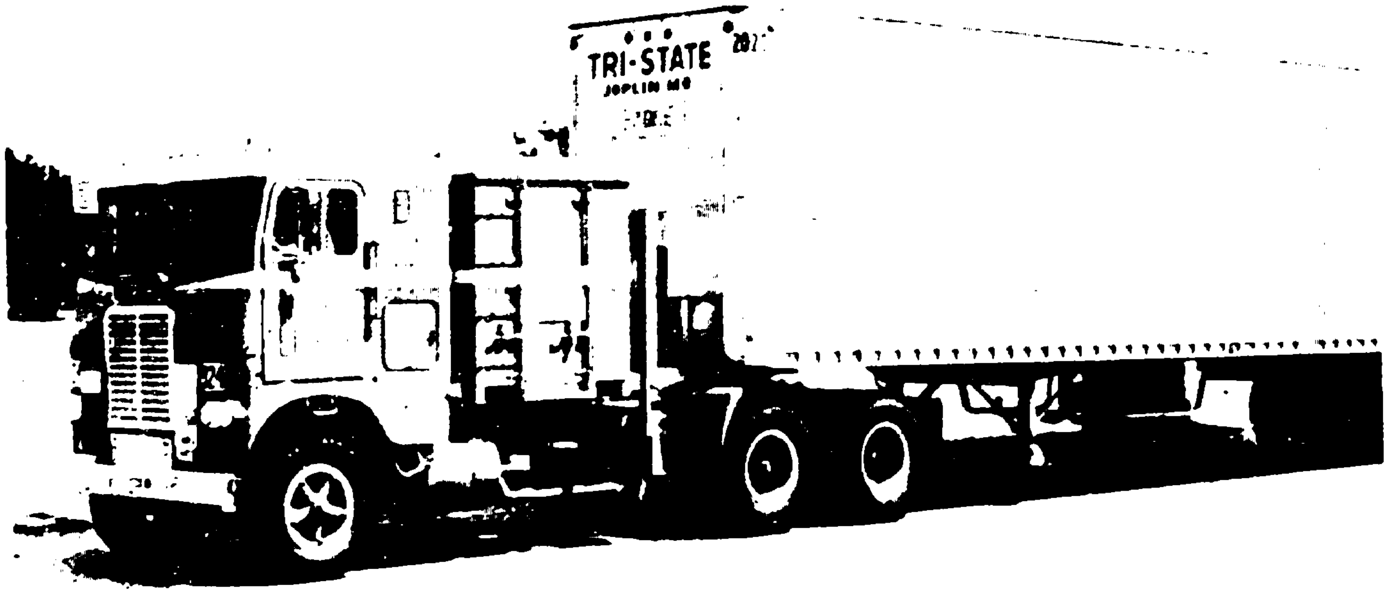
EXPLOSIVES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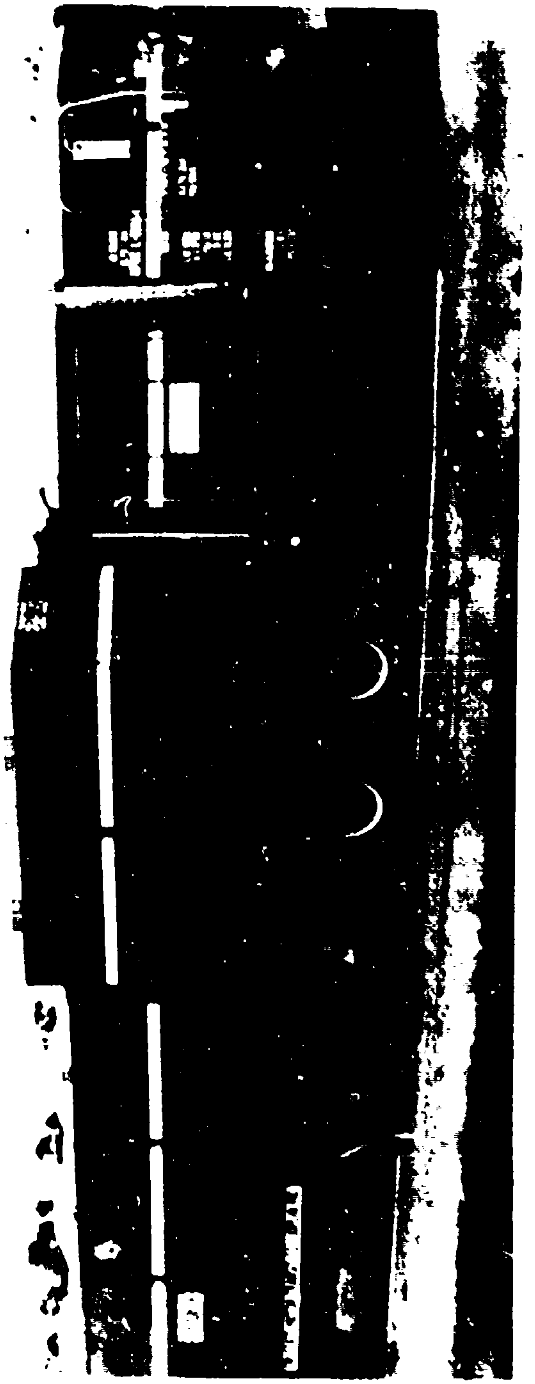


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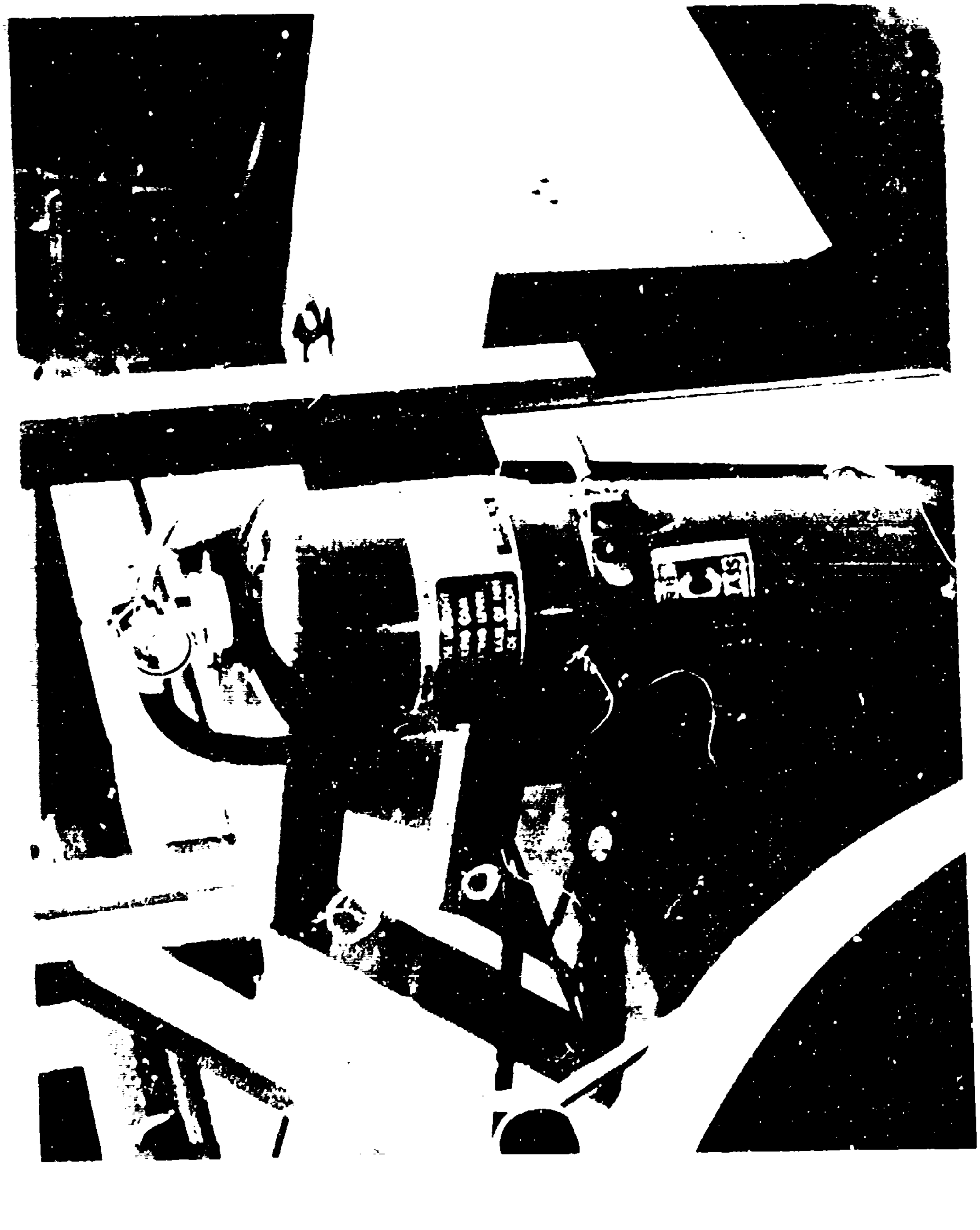

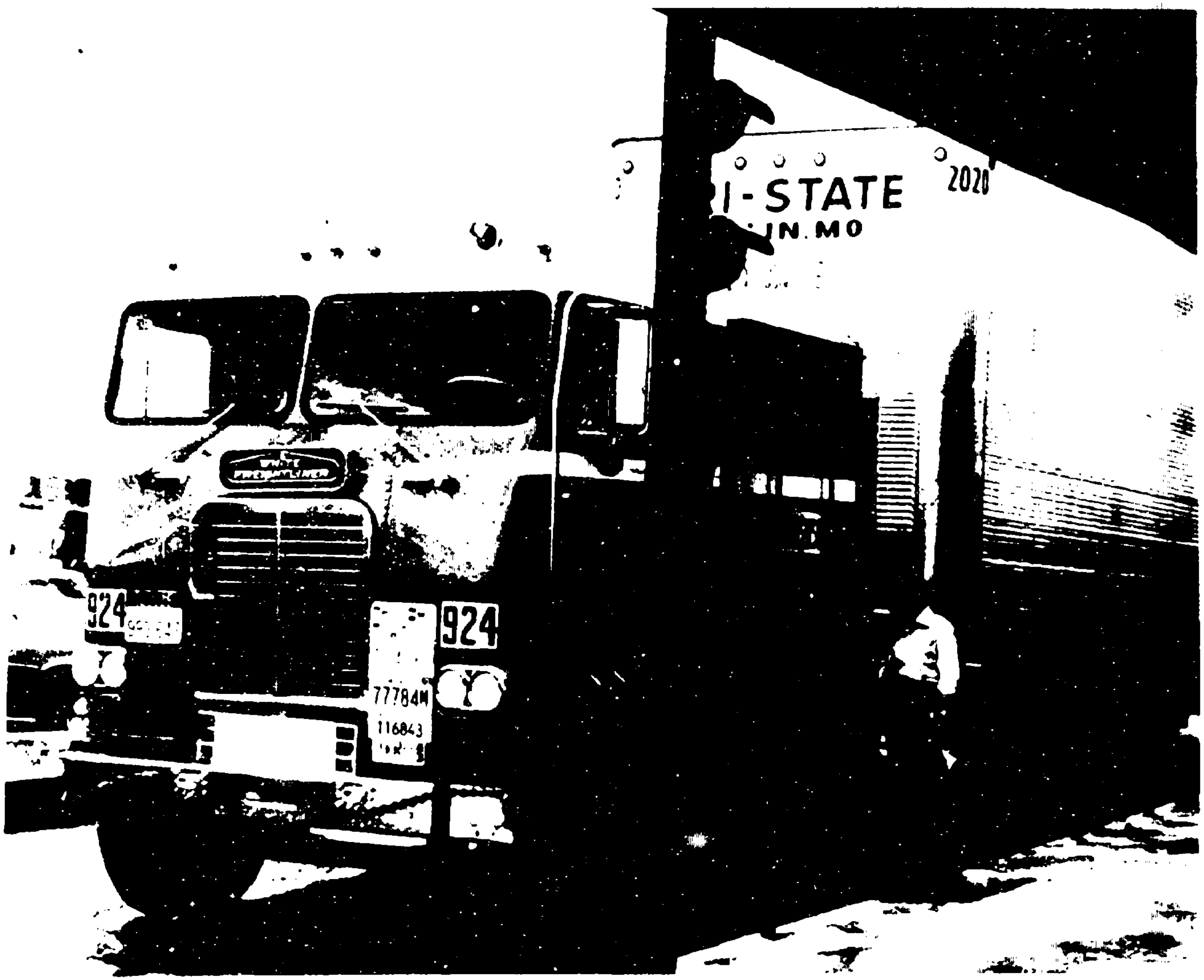

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NEW APPROACHES TO EXPLOSIVE ITEM TRANSPORTATION AND CLASSIFICATION

Phillip J. Smith
Naval Ammunition Depot, Crane, Ind.

The Naval Ammunition Depot, Crane, Indiana wears many hats when the subject of explosive safety is discussed. We are an explosive loader, a long term storage point, and we do both internal and external shipment. In addition, we are the Naval Ordnance Systems Command's design agent for pyrotechnic devices. Wearing this hat Crane is responsible for the design, production and packaging of a number of Explosive Class B items.

It is because of this hat that we in the Research and Development Department became interested in explosive classification, the effect of packaging on this classification and the ultimate dollar cost of shipping.

You will hear a vast amount of discussion today, tomorrow and the next day about the need for improved safety. This is unquestionably a desirable and continuing goal, however, I would like to stress cost - dollars - money.

If we look for a dollar payoff or return from a safety improvement, then we have something to sell that penny pinching project or commodity manager.

This is the line of attack we at Crane are trying to follow.

Our initial work at Crane was with the MK 25 Marine location marker. This is a 15 minute burning pyrotechnic which produces both flame and smoke. The early package was a wooden box weighing 32 lbs. The final pack weighed 2 lbs., occupied 1/2 the volume and cost $2.00 vs. $8.00.

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Obviously, a great savings - provided - that the explosive shipping classification was not changed, thus we became interested in TB 700-2 or NAVORDINST 8020.3; the "Explosive Classification Procedures".

After conducting numerous tests on pyrotechnics, we began wondering if we could obtain lower shipping rates provided that we improved the fire protection we gave ordnance during shipping.

For example, if an unpackaged flare is exposed to a JP4 oil fire, ignition is obtained in one to three minutes. This performance demonstrated that the flare is a Class B special fireworks item.

However, what is the classification? or rather what effect does a fireproof pack have on the shipping rate?

To date we have found no one or no group has any specific guides. We have been told that lower rates for better packs is an interesting question but...pause-gasp-then nothing.

We have never found anyone who would or could say 15 minutes survival time in a fire will give a 10% rate reduction. This question of rate savings for a given fire survival time must be faced at least for Class B and C items if we are going to accomplish anything significant in safer packs.

Before I discuss our latest efforts with the fire retardant plastic foams, I would like briefly to show a few slides of actual classification tests and some different results.

The Code of Federal Regulation: Title 49 - Defines Explosives A, B, and C.

Class A - includes materials which truly detonate such a Tri-Nitro Toluene

Class B - includes materials that burn although we must admit some burning can occur at very high rates.

Class C - includes A or B type materials in very small quantities and depends to a large degree upon judgement of hazard.

These classification tests were conducted with the MK 21, 22, 23, and 24 Submarine Markers. These are smoke markers which burn on the water surface.

SLIDES

Slide 1 - Six markers in a metal container with lockable top.

Slide 2 - Two metal boxes on a wood crib prior to addition of covering wood and kerosene.

Slide 3 - Five markers in a styrene box

Slide 4 - Foam styrene box taped closed

Slide 5 - Two styrene boxes containing ten (10) signals on wood crib.

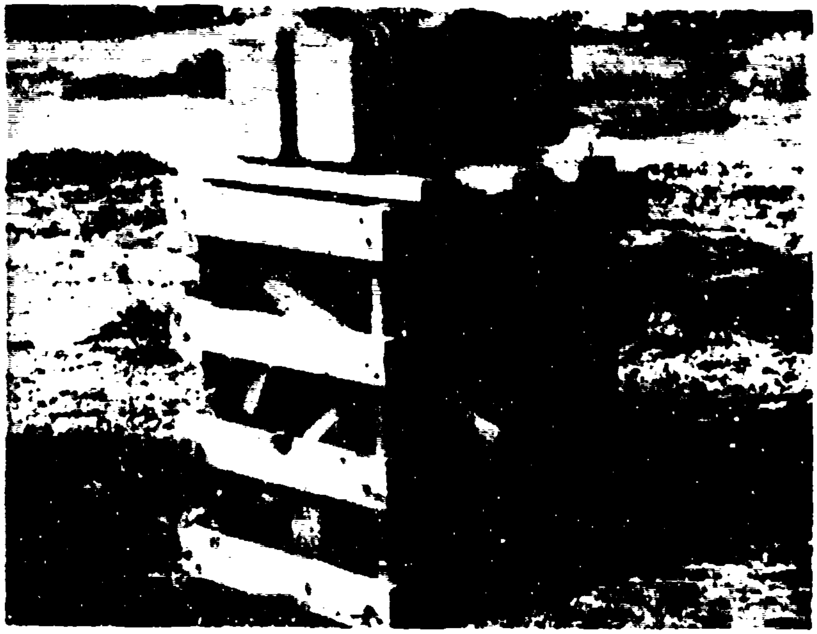
Slide 6 - The remains after the styrene box fire. Steel candle cups, molten aluminum and ashes.

Slide 7 - Smoke produced from Markers, exposed in the metal cans. Note small smoke puff 90 feet away from the bon fire. Burning pyrotechnic and part of metal lid were thrown by an explosion.

Slide 8 - The metal cans after the bon fire test

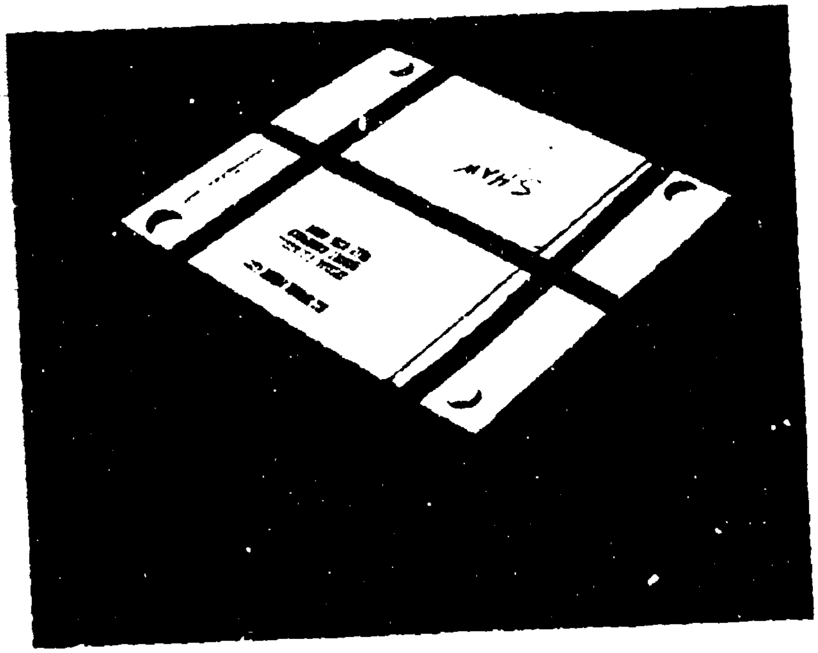
Slide 9 - A box in which one (1) signal was ignited. Part of the box melted and some tape burned

SLIDE 1

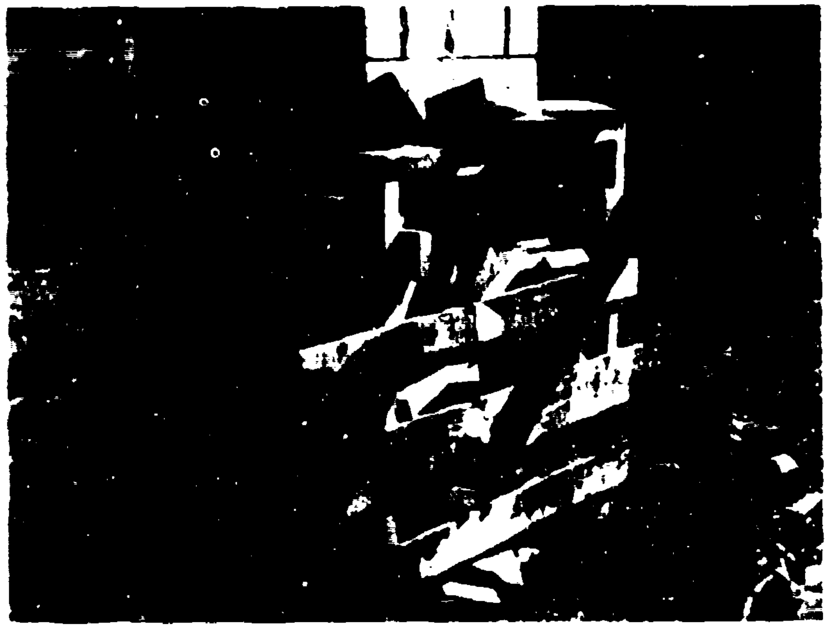


SLIDE 2

SLIDE 3



SLIDE 4



SLIDE 5

SLIDE 6

SLIDE 7

SLIDE 8

SLIDE 9

Slide 10 - A two box stack ready for ignition of the middle signal in the lower box

Slide 11 - Three stacks after ignition of one signal in each stack. Note some melting and damage.

Slide 12 - A metal box after one signal had been ignited. Pressure built up until the lid was blown off

The question generated by the tests shown in these slides is: What is the proper classification for these signals? They are Class B items when packaged in either configuration!

However, the hazard from signals in the metal boxes is obviously greater than the hazard from signals packaged in plastic boxes. Why then should the shipping rates be the same?

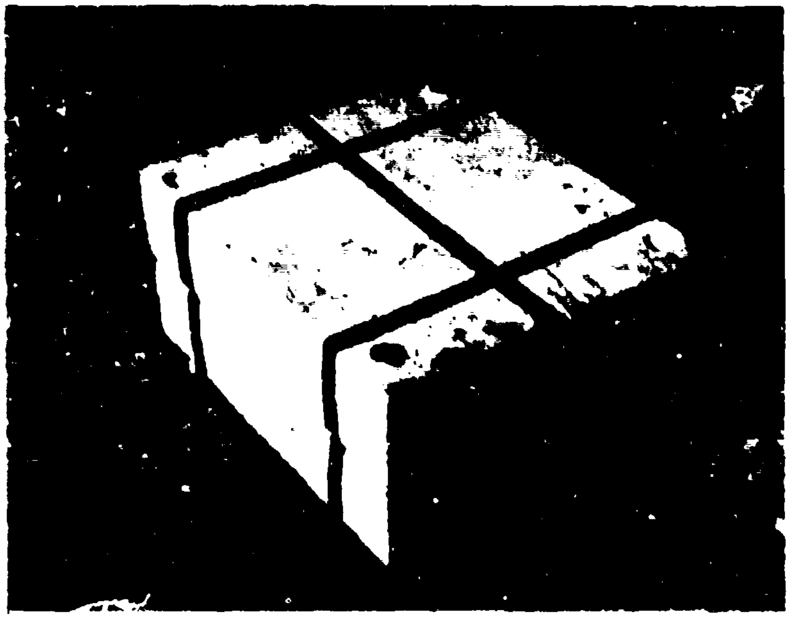
Why shouldn't there be a lower rate for signals packaged in plastic?

At this time, I would like to bring you up-to-date on our latest attempts to develop a fireproof or fire-retardant pack. Our effort centers around a moldable plastic foam based on phenolic resin.

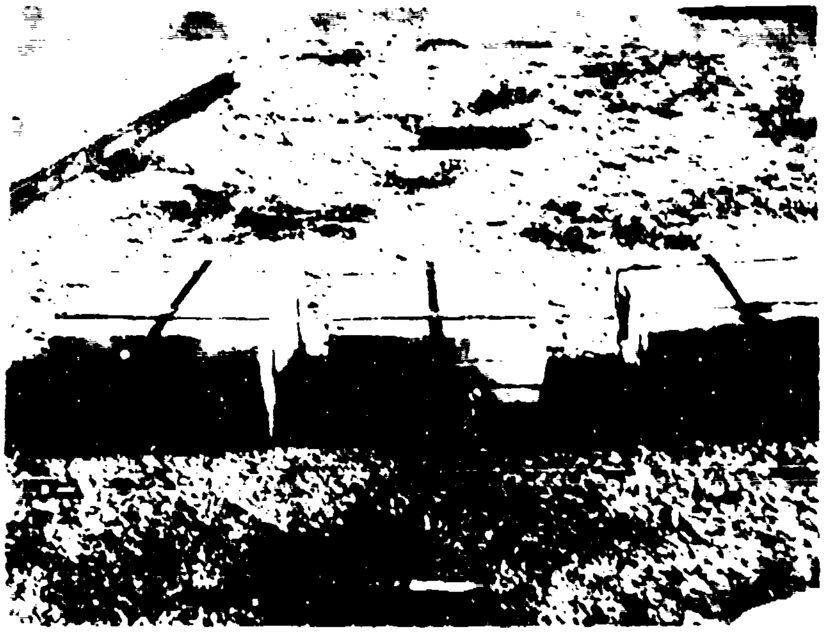
Phenolics have long been known for their resistance to combustion. The foam we are working with was originally developed as an abatative material for missile nose cones. Much of the early work was done for the Atomic Energy Commission.

The foam which can be molded in densities of two (2) to 4.5 pounds per cubic foot. The foam contains:

Phenolic resin
Fiber-glass
Oxalic acid
Boric cenhydride
Freon



SLIDE 10



SLIDE 11

SLIDE 12

The mechanism of how phenolic foam resists fire is comparatively simple. The foam surface chars (burns) and a carbon residue is left in place. Gases evolved from decomposing foam and work their way out through the char, thus removing heat from the char which enables it (the char) to survive the fire.

Our first look with this material was as a container for a Parachute Flare. The flare (MK 24 Mod 1) ignites in 1/2 to 3 minutes after being exposed to an 1800° Fire. A flare packaged in a styrene plastic box may survive slightly longer but ignition can be expected within four (4) minutes.

Slide 13

Here we show a container molded from phenolic. A JP4 fire - which lasted for 17 plus minutes damaged the box.

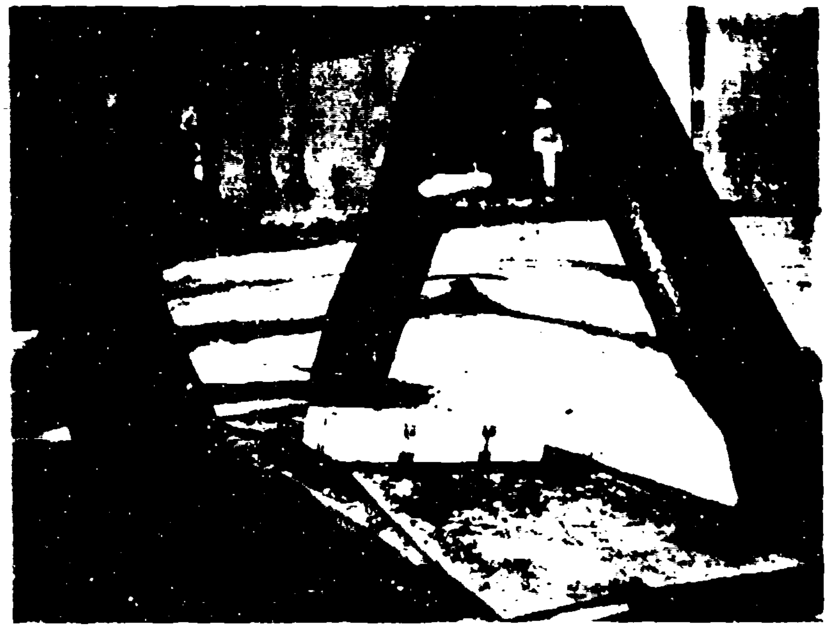
Slide 14 - shows the damaged box which still contained two flares.

The interesting thing is that the flares were not ignited and apparently not damaged. Both flares were subsequently burned. I would not want to tell you that delay times were not affected because we did not measure these; however, the flares survived.

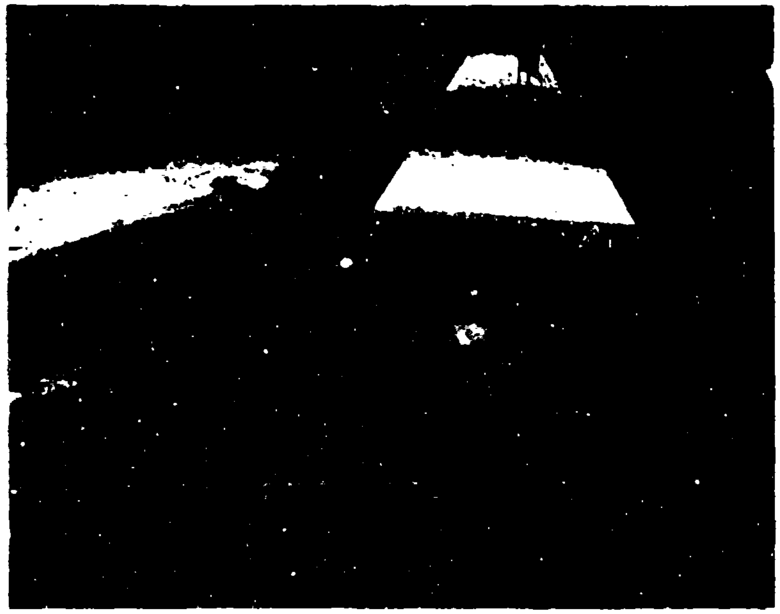
We have progressed down the road towards understanding performance.

Slide 15 - This box was loaded with simulated ordnance instrumented with thermocouples.

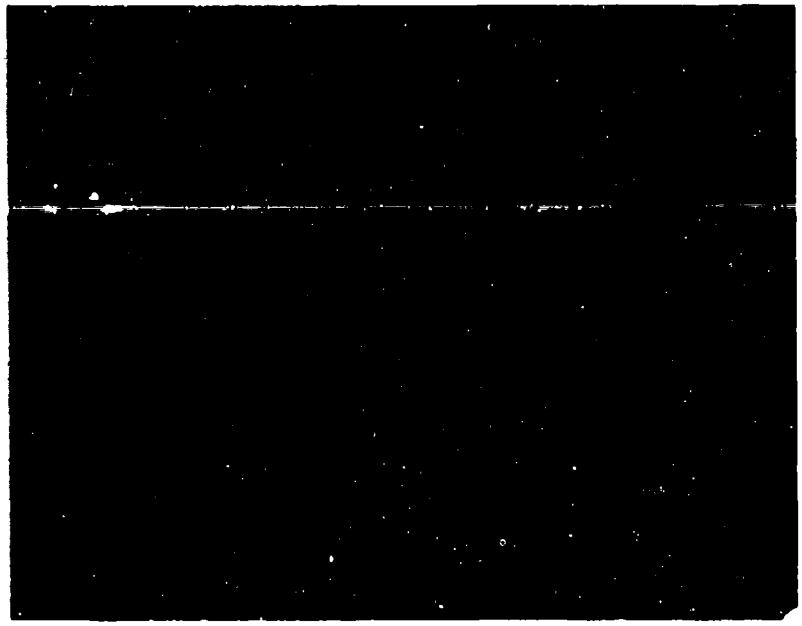
The thermocouples were installed between the metal skin and a fiberboard liner.



SLIDE 13



SLIDE 14



SLIDE 15

Slide 16 - The assembled container closed with steel banded and instrumented with thermocouples for under box and side temperature measurements.

Slide 17 - The fire burning at after 25 minutes

The fire burned out after 28 minutes. The temperature in items 1, 2, and 3 remained at ambient until 18.5 minutes. Item 3 located in the outer cavity started rising at 170°F per minute and reached 1000°F at 23.5 minutes. Item 2 started to rise from ambient at 23 minutes and Item 1 started to rise at 25 1/2 minutes.

The fire went out at 28 minutes when the fuel was consumed.

We have molded 3" blocks and exposed these to a large scale fire test. These tests were done by AVCO Laboratories in Massachusetts.

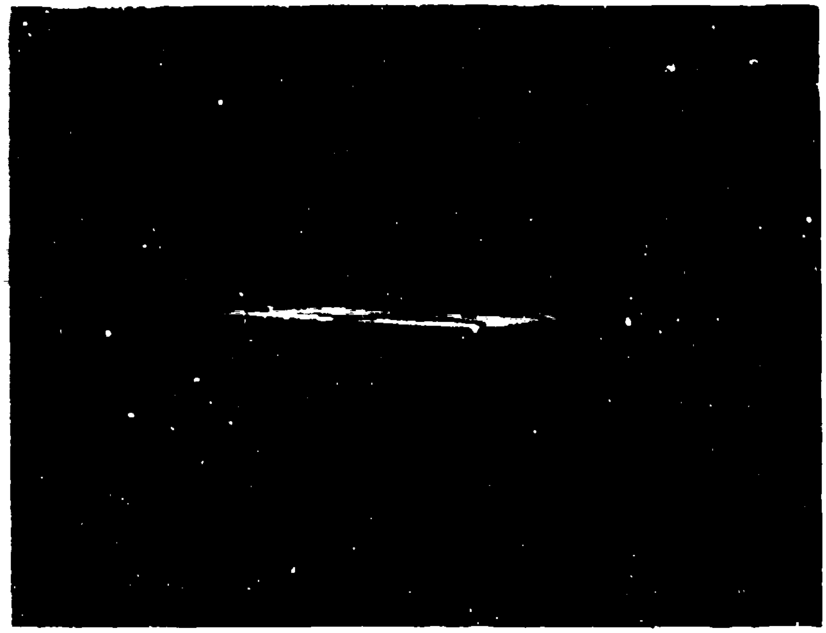
The tests represent a full scale fire which put 9.4 BTU/ft^2/sec of radiant energy into the sample plus 1.6 BTU/ft^2/sec by connection.

The back face is monitored and insulated to prevent heat loss.

A thermocouple 2.9" from the face took 129 minutes to reach 1000°F

It broke 500°F after 106 minutes.

Our work with heat hardening ordnance by developing a fire protective box demonstrates that you can in fact provide long fire survival time. Ordnance which survives 15 or 25 minutes is or should be safer than items which ignite in three (3) minutes. However, we come back to the question of cost or dollar return.



SL:DE 16

SLIDE 17

Most project engineers or commodity managers are willing to invest some money in improved safety; however, there is a limit to which they can or will go.

I feel strongly that there is one area wherein we can and where we should obtain a pay back - that is by a reduced shipping cost.

Either a Class B item or material should be down-graded to Class C and Class C to unregulated when they are packaged for 20 minutes survival time...

If changing the classification is impossible, then a ten (10) to 15 per cent decrease in the published shipping rate is in order. For example, if we pay $7.32 per hundred pounds to ship to the west coast and if there is a 40,000 minimum weight then the cost is $2,928.00. A 10% reduction or $292.00 is not the largest amount; however, it is some token towards paying for increased packaging.

I propose that the Explosive Safety Board, the transportation industry and DOT examine this concept and work out some criteria for levels of fire survival time and that these levels of survival time be attached to a comparable decrease in shipping rates. By doing this, we provide an impetus for safer shipping conditions.

I admit there is one glaring weakness in my argument - that is, the Explosive Safety Board, the transporation industry and DOT would have to work together to implement the system.

The question is do they want improved fire safety enough to warrant a cooperative effort?

ENVIRONMENTAL CONSIDERATIONS IN AMMUNITION DISPOSAL

G. H. Cowan, HQ USA Munitions Command, Dover, N. J.

INTRODUCTION

LAST MARCH, WHEN I WAS SOLICITED FOR A PAPER FOR THIS SEMINAR, I HAD JUST FINISHED AN ASSIGNMENT AS THE CIVILIAN ARMY MEMBER ON A JOINT SERVICE PANEL CONCERNED WITH THE DISPOSAL ASHORE OF CONVENTIONAL AMMUNITION. THIS PANEL WAS FORMED, PRINCIPALLY DUE TO THE RESTRICTION ON DEEP WATER DUMPING, TO DEVELOP A PLAN FOR DISPOSAL OF AMMUNITION BY ECOLOGICALLY ACCEPTABLE MEANS THAT WOULD NOT DEPEND IN ANY MANNER ON DEEP WATER DUMPING.

THE OBJECTIVE OF THE PANEL WAS TO DEVELOP A JOINT SERVICE PLAN TO:

(SLIDE 1) A. SUPPORT A CONTINUING R&D PROGRAM AIMED AT DETERMINING AN ECONOMICAL, CLEAN MEANS TO DISPOSE OF AMMUNITION ASHORE.

B. DEFINE COMMON SERVICE DISPOSAL REQUIREMENTS & RESOURCES.

C. INSURE THAT DISPOSAL FACILITIES ARE SHARED TO THE MAXIMUM EXTENT PRACTICABLE.

D. INCLUDE AND PROVIDE FOR DISPOSAL OF THE CURRENT INVENTORY OF OBSOLETE AND EXCESS CONVENTIONAL MUNITIONS.

ONCE I HAD THE OPPORTUNITY TO SEE THE SUBSTANCE OF THIS SESSION OF THE SEMINAR, AS WELL AS OTHER SESSIONS THIS WEEK, I FOUND IT EXPEDIENT TO ADJUST MY COMMENTS SINCE I HAVE BEEN SCHEDULED AS YOUR FIRST SPEAKER FOR A SESSION DEVOTED FOR THE WHOLE DAY TO THE SUBJECT OF MY PAPER. MY REMARKS, WILL THEREFORE BY INTRODUCTORY, SOMEWHAT GENERAL AND, AS BEST AS I CAN, COMPLEMENTARY TO THE LATER PAPERS OF THE SESSION.

LATER THIS MORNING YOU WILL HEAR MORE ABOUT THE PROBLEMS OF DEEP WATER DUMPING WHICH LED TO OUR PANEL'S ACTIVITY. YOU WILL ALSO RECEIVE MORE DETAILED INFORMATION FROM THE OTHER SPEAKERS ON SOME OF THE SIGNIFICANT AND SPECIFIC ACTIVITIES UNDERWAY TO SOLVE DISPOSAL PROBLEMS.

REQUIREMENTS

BEFORE WE COULD DEVELOP PLANS FOR AMMUNITION DISPOSAL, WE HAD TO DEFINE THE SIZE OF THE PROBLEM. (SLIDE 2) THIS CHART SHOWS THE SITUATION AS IT EXISTED IN JUNE OF 1972. AS CAN BE SEEN, MOST OF THE PROBLEM IS HERE IN THE STATES. THE REASON THERE ARE NO AIR FORCE CONUS STOCKS IS THAT THE ARMY AND NAVY PROVIDE MOST OF THE DEPOT SUPPORT AND THE AF TURNS THEIR EXCESSES BACK TO THESE DEPOTS RATHER THAN DISPOSING OF THEM LOCALLY. THE FUTURE PROJECTIONS ARE ALSO SHOWN TO GIVE YOU SOME MEASURE OF THE WORKLOAD WE FACED.

WORKING WITH TONNAGE ALONE DOESN'T PROVIDE VERY GOOD DISCRIMINATION OF THE KINDS OF AMMUNITION WITH WHICH WE ARE DEALING. CONSEQUENTLY, WE DEVELOPED A SYSTEM OF FAMILY CODES FOR ITEMS OF AMMUNITION HAVING SIMILAR DISPOSAL PROBLEMS OR AMENABLE TO FAIRLY COMMON DISPOSAL PROCEDURES. FOR EXAMPLE, 105 AND 90MM HE AMMUNITION IS BASICALLY SIMILAR WHEN ONE GOES TO DISPOSE OF THEM. EACH FAMILY CODE INDICATES THE GENERAL ITEM AND THE APPROPRIATE METHODS OF DISPOSAL. THIS CHART GIVES AN EXAMPLE OF THE SYSTEM: (SLIDE 3)

P	15	A	D	C
Small Arms Ammo	Zomm	Deactivation Furnace	Burning	Demolition

IDENTIFICATION OF EXCESS STOCKS BY FAMILY CODE IS CONSIDERED ESSENTIAL TO GOOD MANAGEMENT OF THE DISPOSAL PROGRAM.

FACILITIES (SLIDE 4)

THERE ARE BASICALLY FOUR METHODS USED FOR THE DISPOSAL OF CONVENTIONAL AMMUNITION. THESE ARE OPEN BURNING, DETONATION, CONTROLLED THERMAL DECOMPOSITION, (OR INCINERATION) AND WASHOUT. WITHIN THESE FOUR BASIC

METHODS THERE ARE VARIATIONS IN THE EQUIPMENT USED, DEPENDING ON THE TYPE OF MUNITION.

OPEN AIR OR OUTSIDE BURNING IS USED FOR DISPOSAL OF PROPELLANTS, PYROTECHNICS, PROJECTILES, AND NON-PROPULSIVE ROCKET MOTORS. EVEN WHEN EXPLOSIVES ARE REMOVED FROM ITEMS BY OTHER MEANS, WE OFTEN MUST BURN OUT THE TRACE EXPLOSIVE BEFORE WE CAN SELL THE SCRAP. OPEN BURNING OF HAZARDOUS MUNITIONS IN NON-URBAN AREAS IS SPECIFICALLY ALLOWED UNDER THE EXCEPTION CITED IN TITLE 40 OF THE FEDERAL CODE. SOME STATES PROVIDE THE SAME RELIEF, BUT MORE AND MORE A PERMIT IS NEEDED. WHILE THE OFFICIAL ARMY POLICY PROVIDES THAT REQUESTS FOR PERMITS AND ENFORCEMENT WILL BE MADE THROUGH FEDERAL CHANNELS, LITIGATION IS NOW IN PROCESS IN SOME STATES ON THIS MATTER.

NEEDLESS TO SAY, THE DEPOT COMMANDER IS CAUGHT IN THE MIDDLE OF ALL OF THIS SINCE HE IS ALSO CHARGED BY REGULATION TO COOPERATE WITH THE LOCAL COMMUNITY IN THEIR POLLUTION CONTROL PROGRAMS. THIS NEXT SLIDE SHOWS A TYPICAL BURNING GROUND. (SLIDE 5)

OPEN BURNING CREATES EXCESSIVE SMOKE, NOXIOUS FUMES AND IS ESTHETICALLY UNDESIRABLE. IN MOST INSTANCES, INVESTMENT IN PROPER FACILITIES USING PRESENT STATE-OF-THE-ART TECHNOLOGY CAN REPLACE THE TRADITIONAL BURNING GROUND AT OUR DEPOTS. OUR OBJECTIVE IS TO ELIMINATE ALL ROUTINE OPEN BURNING AND RETAIN THE TECHNIQUE ONLY WHERE SAFETY DOES NOT PERMIT EXPOSING PERSONNEL OR EQUIPMENT TO POTENTIAL DAMAGE. (SLIDE 6)

DETONATION IS ACCOMPLISHED BY PLACING EXPLOSIVE ITEMS IN PITS, AFFIXING INITIATING AND PRIMING DEVICES SUCH AS DEMOLITION EXPLOSIVES TO THEM, AND FIRING BY A BLASTING MACHINE FROM BEHIND A BARRICADE. IN MANY INSTANCES, EXPLOSIVE ITEMS MUST BE BURIED FROM 2 TO 10 FEET UNDER EARTH TO MINIMIZE NOISE. ITEMS USUALLY DETONATED INCLUDE BULK EXPLOSIVES,

MINES, LARGE CALIBER PROJECTILES, BOMBS, PHOTOFLASH ITEMS, ROCKETS, ETC.

THE ONLY POLLUTION OF CONSEQUENCE IS AIR-BORNE SOLIDS AND GASES, SOME OF WHICH MAY BE TOXIC, SUCH AS LEAD COMPOUNDS, AND THE ACCOMPANYING NOISE AND SHOCK. THERE IS VERY LITTLE EMISSION OF AIR POLLUTANTS IN THE SENSE IN WHICH WE NORMALLY THINK. (E.G., A PROCESS STACK IN A REFINERY). SAFETY, NOISE, SHOCK AND FALLOUT PARAMETERS ARE GENERALLY CONTROLLING IN THIS OPERATION.

THE LARGE DEPOTS IN THE WEST HAVE THE MOST FLEXIBILITY FOR THIS OPERATION. LIMITATIONS WHICH DO EXIST WERE ESTABLISHED FOR SEVERAL REASONS:

1. SPECIFIC QUANTITY--DISTANCE RESTRICTIONS.
2. SPECIAL VIBRATION AND CHANNELING OF THE NOISE AND SHOCK ASSOCIATED WITH THE GEOLOGY AND GEOGRAPHY OF THE DEPOT IN RELATION TO INHABITED AREAS.
3. COMPLAINTS AND SUITS WHICH HAVE OVER THE YEARS GENERATED LOCAL RESTRICTIONS, OFTEN DUE TO POLITICAL RATHER THAN SCIENTIFIC FACTORS.

EVEN WHEN NO LIMIT IS SPECIFIED, INSTALLATIONS DO NOT NORMALLY EXCEED 25,000 LBS. TNT EQUIVALENT, WITHOUT SPECIAL PERMISSION. THIS METHOD IS ALSO LIMITED BY WEATHER CONDITIONS TO CONTROL FALLOUT AND NOISE.

DETONATION IS NOT USED WHEN THERE IS VALUE IN RECOVERING COMPONENTS AND WILL PROBABLY BECOME ECOLOGICALLY LESS ATTRACTIVE IN THE FUTURE. HOWEVER, IT IS THE ONLY SAFE WAY OF DISPOSING OF SOME ITEMS WHICH ARE BADLY DETERIORATED AND CANNOT BE MOVED OFF-POST. OUR OBJECTIVE IS TO REDUCE DEMOLITION TO A MINIMUM IN THE FUTURE.

CONTROLLED THERMAL DESTRUCTION OR INCINERATION IS A WIDELY USED TECHNIQUE FOR THE DISPOSAL OF A GREAT VARIETY OF MUNITIONS SUCH AS FUZES, BOOSTERS, PRIMERS AND SMALL ARMS AMMUNITION. THERE ARE TWO BASIC

TYPES IN USE AT OUR DEPOTS. THE SO-CALLED "POPPING FURNACE", AN EXTERIOR VIEW OF WHICH IS SHOWN HERE, (SLIDE 7) IS USED FOR THE HIGH VOLUME DEMILITARIZATION OF SMALL ARMS AMMUNITION CARTRIDGE CASES. SPENT OR EXCESS PRIMED CASES ARE FED IN ONE END AND THE BRASS OR STEEL READY FOR SALE AS SCRAP COMES OUT THE OTHER END. THIS PROCESS ASSURES THAT NONE OF THE CASES LEAVES THE PLANT CONTAINING ANY EXPLOSIVE CONTAMINATION. THE PICTURE SHOWS THE FACILITY AT SAVANNA WITH A LARGE COOLING TOWER THROUGH WHICH THE CASES MOVE FROM THE FURNACE PRIOR TO DISCHARGE INTO A BIN OR DIRECTLY INTO A TRUCK OR BOX CAR.

BY FAR THE MOST SIGNIFICANT PIECE OF EQUIPMENT USED AT THE DEPOTS IS THE "DEACTIVATION FURNACE." THE FACILITY AT SAVANNA IS SHOWN ON THIS SLIDE. (SLIDE 8)

THIS IS AN EXTREMELY VERSATILE PIECE OF EQUIPMENT. LAST YEAR AT SAVANNA I OBSERVED EXCESS CALIBER 45 SLUGS IN THEIR CONTAINERS BEING FED FROM THE BUILDING ON THE RIGHT ALONG THE CONVEYOR INTO THE FURNACE. AT A DISCHARGE PORT BY THE SIDE DOOR, LIQUID LEAD WAS POURING INTO INGOT MOLDS READY TO BE SOLD AS SCRAP METAL. AN INTERIOR SHOT OF THE FURNACE IS SHOWN HERE. (SLIDE 9)

THIS IS A FOUR-BARREL DESIGN, SO-NAMED FOR THE FOUR SECTIONS PROVIDING RESIDENCE TIME AND CAPACITY SUFFICIENT TO ASSURE THE BURNING OF ALL OF THE ENERGETIC MATERIAL IN THE MUNITION FED INTO THE FURNACE. IN ADDITION TO THE SMALLER ITEMS I MENTIONED, THESE FURNACES ARE USED TO FLASH METAL PARTS FROM WASHOUT OPERATIONS TO ASSURE THAT ALL OF THE EXPLOSIVE IS CONSUMED BEFORE SALE AS SCRAP.

TWO YEARS AGO IN SAN DIEGO, MR. CRIST FROM TOOELE ARMY DEPOT GAVE A PRESENTATION OF WORK HE WAS DOING TO DISPOSE OF LARGE ITEMS OF MUNITIONS BY CUTTING OR SAWING THEM INTO PIECES SUITABLE FOR THE CAPACITY OF THE FURNACE. THE KEY TO THIS TECHNIQUE IS EXPOSING THE EXPLOSIVE SUFFICIENTLY

SO THAT IT WILL BURN RATHER THAN DETONATE. I REFER YOU TO THE MINUTES OF THE 1971 MEETING FOR DETAILS ON THIS.

ALL OF THE ARMY DEPOTS ARE EQUIPPED WITH, OR PROGRAMMED TO RECEIVE, HEAVY-DUTY DEACTIVATION FURNACES. WITH PROPER DESIGN OF STACK EMISSION TREATMENT, THIS TECHNIQUE SHOULD MEET OUR CURRENT AND EXPECTED STANDARDS FOR SOME TIME TO COME. IT SHOULD BE EMPHASIZED, HOWEVER, THAT SUCH STACK ABATEMENT EQUIPMENT, WHILE BASICALLY WITHIN THE STATE-OF-THE-ART, IS NOT AVAILABLE OFF-THE-SHELF, AND WILL REQUIRE EXTENSIVE DESIGN AND TESTING BEFORE BROAD APPLICATION AT THE DEPOTS.

THERE ARE DISADVANTAGES TO FURNACES. THE DANGER OF DETONATION IS ALWAYS PRESENT. ALSO, THE TECHNIQUE CAN'T BE USED WHEN YOU WISH TO RECOVER THE METAL PARTS OR EXPLOSIVE FOR REUSE.

THE FOURTH METHOD OF DISPOSAL IS WASHOUT. THE TECHNIQUE EVOLVED AS A METHOD TO RECLAIM GOOD METAL PARTS FROM OTHERWISE FAULTY PROJECTILES. IT IS WIDELY USED AT OUR LOADING PLANTS AND DEPOTS.

(SLIDE 10) A TYPICAL FACILITY IS SHOWN ON THIS SLIDE. NEXT IS AN INTERIOR VIEW. (SLIDE 11) PROJECTILES ARE LOWERED INTO FIXTURES ATOP THE EQUIPMENT AND HOT WATER OR STEAM IS FORCED INTO THE PROJECTILE, MELTING THE TNT OR COMP B OUT OF THE SHELL BODY. THE EXPLOSIVE COLLECTS BELOW AND IS PUMPED TO AN ADJOINING BAY WHERE IT IS SEPARATED FROM THE WATER, FLAKED OR PELLETIZED AND DRIED. THE PRODUCT HAS A CURRENT SALE VALUE OF APPROXIMATELY TWENTY CENTS PER POUND.

(SLIDE 12) THE NEXT SLIDE SHOWS THE WATER RECYCLE SYSTEM. THE ONLY EFFLUENT IS A TNT CONTAMINATED "PINK WATER" WHICH, WHILE NOT PARTICULARLY DANGEROUS, DOES REQUIRE TREATMENT.

WASHOUT PLANTS ARE USED TO HANDLE LARGER ITEMS WHERE THERE IS A SIGNIFICANT AMOUNT OF EXPLOSIVE TO BE RECOVERED OR WHERE THE NEED FOR

THE METAL PARTS IS PARAMOUNT. A FACILITY DESIGNED FOR WHITE PHOSPHORUS WHICH PERFORMS A SIMILAR FUNCTION IS AVAILABLE AT PINE BLUFF ARSENAL IN ARKANSAS.

MOST DISPOSAL METHODS REQUIRE THAT CERTAIN OPERATIONS BE PERFORMED TO PREPARE OR CONDITION AMMUNITION ITEMS FOR THE DISPOSAL OPERATION. THESE OPERATIONS RANGE FROM EXPOSING THE END ITEM BY UNPACKING AND PARTIAL DISASSEMBLY, TO EXPOSING EXPLOSIVES AND SEPARATING DISSIMILAR MATERIALS TO ENHANCE SCRAP VALUE.

(SLIDE 13) THE PURPOSE OF DISASSEMBLY IS TO:

1. RECOVER SERVICEABLE OR SALABLE MATERIALS OR COMPONENTS SUCH AS PROPELLANT AND BRASS CARTRIDGE CASES.
2. PROVIDE ACCESS TO FILLERS SUCH AS REMOVING BASE PLATES FROM BOMBS TO ALLOW WASHOUT.
3. ISOLATE OR SEGREGATE HAZARDOUS COMPONENTS SUCH AS DEFUZING PRIOR TO FURTHER PROCESSING.

A WIDE RANGE OF EQUIPMENT IS AVAILABLE FOR THESE OPERATIONS. SOME ARE SPECIFIC, SUCH AS ROTARY BULLET PULL-APART MACHINES FOR SMALL ARMS AMMUNITION OR BASE PLATE REMOVAL MACHINES FOR BOMBS. MUCH OF THIS EQUIPMENT IS ALSO USED FOR AMMUNITION MAINTENANCE OPERATIONS.

TECHNOLOGY

IN STUDYING THE SUBJECT OF AMMUNITION DISPOSAL, ONE POINT BECAME QUITE APPARENT. ALTHOUGH CONSIDERABLE RESOURCES WERE BEING INVESTED IN TECHNOLOGY RELATED TO POLLUTION ABATEMENT WHICH IS DIRECTLY APPLICABLE TO THE PROBLEMS ENCOUNTERED IN AMMUNITION DISPOSAL, VERY LITTLE OF IT WAS ORIGINALLY UNDERTAKEN WITH THIS OBJECTIVE IN MIND. AMONG THE THREE SERVICES, UNTIL RECENTLY, THE R&D COMMUNITY LOOKED UPON DISPOSAL AS SOMETHING THAT SOMEONE ELSE DID IN THE NORMAL COURSE OF EVENTS. THERE

WAS LITTLE MOTIVATION IN MAKING ITEMS EASIER TO DISASSEMBLE OR DE-MILITARIZE.

TWO RELATED EVENTS CHANGED THIS SITUATION. FIRST, THE MORATORIUM ON DEEP WATER DUMPING CREATED A MINOR CRISIS IN THE SERVICES, PARTICULARLY THE NAVY, SINCE THEIR PRIMARY AND RELATIVELY CHEAP METHOD OF DISPOSING OF BULKY, DIFFICULT-TO-HANDLE MUNITIONS WAS NO LONGER AVAILABLE TO THEM. SECONDLY, THE DECISION TO REDUCE OUR STOCKPILE OF OFFENSIVE TOXIC CHEMICAL MUNITIONS BROUGHT TO LIGHT THE EXTREME DIFFICULTY OF RAPIDLY DISASSEMBLING AND SEGREGATING THE TOXIC COMPONENTS TOGETHER WITH THE MONUMENTAL PROBLEM OF DISPOSING OF THESE AGENTS WITHOUT CREATING HAZARDOUS POLLUTION OR CONTAMINATION.

ONE FOUND THAT THERE WERE FEW FORMAL R&D PROGRAMS, PARTICULARLY IN THE ARMY SPECIFIC TO CONVENTIONAL AMMUNITIONS DISPOSAL PROBLEMS. THIS SITUATION IS NOW CHANGING. HOWEVER, MOST OF THE ADVANCES ARE STILL COMING AS OUTGROWTHS OF OTHER PROGRAMS.

I WOULD NOW LIKE TO COVER, BRIEFLY, SOME OF THE APPROACHES BEING UNDERTAKEN BY THE ARMY TO IMPROVE OUR CAPABILITY TO DISPOSE OF AMMUNITION WITHOUT POLLUTION.

PERHAPS THE MOST EXTENSIVE EFFORTS ARE BEING DIRECTED TOWARD ELIMINATING THE OPEN BURNING OF ENERGETIC WASTES. AT THE DEPOT LEVEL, WE HAVE SPECIFIC INCINERATION ENGINEERING AND CONSTRUCTION PROGRAMS NOW UNDERWAY. AT PINE BLUFF, A PROTOTYPE INCINERATOR IS BEING DESIGNED TO HANDLE PYROTECHNICS INCENDIARY AND RIOT-CONTROL ITEMS AS WELL AS CONTAMINATED NON-TOXIC WASTE MATERIALS. AT SAVANNA ARMY DEPOT AN INCINERATOR IS BEING BUILT THAT WILL BE CAPABLE OF HANDLING LARGE AMMUNITION ITEMS AS WELL AS A HOST OF SMALLER ITEMS AND BULK ENERGETIC MATERIALS. THESE INCINERATORS ARE OF DIFFERENT DESIGN FOR DIFFERENT PURPOSES. WE ALSO HAVE A PROGRAM AT

TOOELE TO DESIGN A CONTROL AND ABATEMENT SYSTEM FOR USE WITH CONVENTIONAL DEACTIVATION FURNACES TO REDUCE THE DISCHARGE OF NITROGEN AND SULFUR OXIDES AND PARTICULATE MATTER INTO THE ATMOSPHERE.

TO SUMMARIZE THIS WORK BRIEFLY, TOOELE HAS OBTAINED EMISSION DATA FROM BURNING A LARGE VARIETY OF MUNITIONS. THEY HAVE EXPLORED MODIFICATIONS TO FURNACE OPERATION PROCEDURES AS A METHOD OF REDUCING POLLUTANT EMISSIONS AND ARE CURRENTLY PREPARING PRELIMINARY SPECIFICATIONS FOR PROCUREMENT OF A PROTOTYPE AIR POLLUTION CONTROL SYSTEM. WORK IN THE AREA OF NO_x MEASUREMENT IS UNDERWAY USING A CONTINUOUS ANALYZER WHICH OPERATES ON THE PRINCIPLE THAT A CHEMILUMINESCENT REACTION WITH OZONE IS DIRECTLY PROPORTIONAL TO NO_x CONCENTRATION. THIS SLIDE SHOWS A VIEW OF THE PROBE USED WITH THIS SYSTEM. (SLIDE 14)

A VERY SUBSTANTIAL BODY OF WORK IS UNDERWAY TO DESIGN EXPLOSIVE WASTE INCINERATORS FOR OUR AMMUNITION PRODUCTION PLANTS. WHILE THESE PLANTS ARE CONCERNED WITH THE DISPOSAL OF SCRAP OR REJECT COMPONENTS FROM THE PRODUCTION PROCESS, THE TECHNOLOGY IS DIRECTLY APPLICABLE AND WE EXPECT THAT THE BASIC DESIGNS WILL BE USED IN OUR DEPOTS AS WELL AS FOR THE DESTRUCTION OF BULK EXPLOSIVES AND PROPELLANTS.

EXPLOSIVE AND PROPELLANT WASTE INCINERATION MUST BE VIEWED AS A SYSTEM. (SLIDE 15) THE WASTE MUST BE PREPARED AS A SLURRY WITH WATER AND SAFELY TRANSFERRED TO THE COMBUSTION REGION. COMBUSTION MUST BE STABLE AND CONTINUOUS. ALL EMISSION PRODUCTS MUST BE CONTAINED WITHIN ACCEPTABLE LEVELS TO MEET STANDARDS. THE SYSTEM SHOULD BE UNDER CONTINUOUS MONITORING THROUGH SAMPLING AND ANALYSIS TO INSURE ATTAINING DESIGN OBJECTIVES.

(SLIDE 16) A ROTARY KILN INCINERATOR, THE SYSTEM FURTHEST ALONG IN DEVELOPMENT, HAS BEEN PILOTED AND IS IN OPERATION AT RADFORD ARMY

AMMUNITION PLANT. RADFORD HAS SUCCESSFULLY DISPOSED OF SINGLE, DOUBLE, AND TRIPLE BASE PROPELLANTS, ALUMINIZED PROPELLANTS, TNT AND HMX WITH NO_x EMISSION LEVELS BELOW 200ppm.

(SLIDE 17) A PILOT INCINERATOR WORKING ON AN INDUCED DRAFT PRINCIPLE, WAS SUCCESSFULLY OPERATED AT PICATINNY ARSENAL. TESTS HAVE BEEN COMPLETED USING TNT, COMP B, RDX AND HMX SLURRIES. TEMPERATURE AND PHOTOGRAPHIC DATA FOR TNT SHOWED CONTROLLED, RAPID COMBUSTION OCCURRING IN THE INJECTION AND COMBUSTION ZONES OF THE INCINERATOR WITH ONLY AN OCCASIONAL FLAMING PARTICLE VISIBLE.

ANOTHER APPROACH IS A FLUIDIZED BED CONCEPT WHICH HAS BEEN DEMONSTRATED IN LABORATORY SCALE EQUIPMENT UNDER CONTRACT WITH ESSO RESEARCH AND ENGINEERING CO. PRELIMINARY RESULTS USING A CATALYST WITH THE BASIC BED MATERIAL INDICATE A DRASTIC REDUCTION IN NO_x GENERATION WELL WITHIN THE PROJECTED STANDARD OF 200ppm. DESIGN MODIFICATION DRAWINGS FOR CONVERTING THE PICATINNY INCINERATOR TO A FLUID BED REACTOR, AS SHOWN HERE, HAVE BEEN COMPLETED. (SLIDE 18)

ASIDE FROM WHOLLY ENERGETIC MATERIALS, A PROBLEM EXISTS IN DISPOSING OF INERT WASTE (SUCH AS PACKAGING MATERIALS) WHICH HAVE BECOME CONTAMINATED WITH EXPLOSIVES. THE USUAL METHOD OF DISPOSAL IS BY OPEN BURNING. JOLIET ARMY AMMUNITION PLANT HAS EVALUATED A COMMERCIAL SYSTEM FOR THIS PURPOSE. THE SYSTEM, MODIFIED TO INCLUDE SAFETY RELIEF FEATURES, HAS A CAPABILITY OF HANDLING 600 LBS./~~TONS~~ HR OF WASTE MATERIAL. (SLIDE 19)

TESTS WERE CONDUCTED USING INERT WASTE AND EXPLOSIVE CONTAMINATED INERT WASTE TO DETERMINE OPTIMUM TEMPERATURE AND FEED RATES. IN

ADDITION, AN EVALUATION OF THE INCINERATOR BURNING CONTAMINATED WASTES WAS CONDUCTED BY THE ARMY ENVIRONMENTAL HYGIENE AGENCY AT JOLIET LAST DECEMBER. THE EMISSIONS FROM THE STACK WERE WELL BELOW THE STATE OF ILLINOIS STANDARDS FOR PARTICULATES, CO AND NO_x. RESULTS OF THIS PROGRAM HAVE BEEN PUBLISHED AND CAN BE OBTAINED FROM PICATINNY ARSENAL.

ANOTHER AREA OF CONCERN IS THE SO-CALLED "PINK WATER" PROBLEM. THIS PROBLEM IS COMMON TO BOTH DEPOTS AND LOADING PLANTS WHERE TNT COMES INTO CONTACT WITH , AND A PORTION IS DISSOLVED IN WATER. THROUGH A COMPLEX PROCESS OF PHOTO-CHEMICAL ACTION, INTENSIFIED BY RAISING THE pH LEVEL, THE WASH WATER TURNS AN ORANGE OR LIGHT RUST COLOR, WHICH WE CALL "PINK" WATER.

TO PRECLUDE ITS FORMATION, ACTIVATED CARBON IN AN EXTRACTION COLUMN HAS BEEN FOUND TO REDUCE THE TNT FROM OVER 100ppm TO AS LOW AS 0.05ppm ON THE DISCHARGE SIDE. UNFORTUNATELY, ONCE THE CARBON BECOMES SATURATED WITH TNT, ITS CAPABILITY FOR EXTRACTION IS LOST. THE SPENT CARBON MUST THEN BE DISPOSED OF BY OPEN BURNING, WHICH JUST TRANSFERS THE POLLUTANT FROM THE STREAMS TO THE ATMOSPHERE. THIS SLIDE SHOWS A REGENERATION PROCESS NOW BEING STUDIED. (SLIDE 20)

WHEN THE CARBON COLUMN IS SATURATED, IT IS TAKEN OFF-STREAM AND TOLUENE IS PASSED THROUGH IT TO DISSOLVE THE TNT. NOW WE MUST FIND A WAY TO EXTRACT TNT. AN APPROACH BEING CONSIDERED IS LOW TEMPERATURE CRYSTALLIZATION. THE TNT SETTLES OUT AND CAN BE RECOVERED, WASHED AND RECYCLED INTO THE DRYING OPERATION OF THE WASHOUT PLANT OR, IN THE CASE OF A LOADING PLANT, PUT BACK INTO THE LINE.

FOR MONITORING "PINK WATER" A PHOTOMETRIC ANALYZER WAS ADAPTED BY REPLACING THE OPTICAL FILTERS IN THE STANDARD INSTRUMENT WITH

ONES THAT ARE ABSORBED AT WAVELENGTHS APPROPRIATE TO TNT. (SLIDE 21)

WE MODIFIED THE CELLS IN THE MEASURING AND REFERENCE CHANNELS TO BE OF THE PROPER PATH-LENGTH FOR THE REQUIRED MEASUREMENT AND OF THE PROPER CONSTRUCTION FOR USE IN AN AQUEOUS MEDIUM.

WASHOUT WORKS FINE FOR TNT AND COMP B, BUT NOT SO WELL FOR MINOL USED IN BOMBS. ONCE YOU GET AMMONIUM NITRATE DISSOLVED IN WATER, YOU CAN KISS IT GOODBYE. THE TECHNOLOGY FOR RECOVERY OF SOLUBLE NITRATES IS STILL IN THE RESEARCH STAGE UNLESS YOU WANT TO USE COPIOUS AMOUNTS OF HEAVY METALS. BIODEGRADATION AND VARIOUS EXCHANGE RESIN BEDS ARE BEING STUDIED, BUT NONE ARE AVAILABLE FOR USE TODAY.

TOOELE IS WORKING ON A SYSTEM TO RECLAIM MINOL FROM 750 POUND BOMBS BY USING THE TECHNIQUE OF MICROWAVE MELTING. THE EXPLOSIVE MELTS AT 176° F. THERE ARE PROBLEMS, HOWEVER. THE EXPLOSIVE ABILITY TO ABSORB HEAT INCREASES WITH TEMPERATURE. ONE MUST BE CAREFUL NOT TO GET HOT SPOTS INSTEAD OF UNIFORM HEATING. A SCHEMATIC OF THE SYSTEM IS SHOWN HERE. (SLIDE 22)

IN SUMMARY, OUR PANEL HIGHLIGHTED THE PROGRAMS I HAVE DISCUSSED AS WELL AS OTHERS, SOME OF WHICH WILL BE COVERED TODAY, WHICH REQUIRE SUPPORT TO ACHIEVE THE OVERALL OBJECTIVES OF CLEAN DISPOSAL. TWO AREAS NEED SPECIAL EMPHASIS.

FIRST, IT IS VERY IMPORTANT THAT THE PROBLEMS OF DISPOSAL BE CONSIDERED WHEN DESIGNING AMMUNITION. WE HAVE RECOMMENDED THAT THIS BE A SPECIFIC CHECK POINT IN THE DESIGN REVIEW OF ALL DEVELOPMENT AND PRODUCT IMPROVEMENT PROGRAMS. THE MAINTENANCE ENGINEER MUST TAKE A LOOK AT THE DEPOTS' PROBLEM IF AND WHEN THE MUNITION HAS SERVED ITS PURPOSE OF DEFENSE READINESS AND IS NO LONGER NEEDED. METHOD OF DIS-ASSEMBLY, USING STANDARIZED TOOLS WHERE POSSIBLE, PROVISION OF SPECIAL

TOOLS, OR SCHEMATICS OF TEAR DOWN EQUIPMENT SHOULD BE A PART OF THE DEVELOPER'S TECHNICAL DATA.

MUCH WAS SAID IN THE REPORT ABOUT RECYCLE. I WISH TO SAY CATEGORICALLY THAT I SUPPORT THIS APPROACH, BUT WE MUST NOT BE MISLED. UNFORTUNATELY, PERIODS OF HEAVY DEMILITARIZATION AND DISPOSAL OPERATIONS DO NOT ALWAYS CORRESPOND IN TIME OR LOCATION TO PERIODS OF HEAVY PRODUCTION OR RENOVATION. I KNOW OF MANY RECYCLE SCHEMES THAT ARE VERY PRACTICAL IF YOU HAVE A RECEIVING PROCESS INTO WHICH THE COMPONENTS CAN BE PUT. FOR EXAMPLE, EXPLOSIVES CAN BE REUSED IF YOU ARE LOADING AMMUNITION SOMEWHERE NEARBY, BUT IF YOU MUST PACKAGE IT, SHIP AND STORE IT FOR FUTURE USE, THE ECONOMICS CAN OFFSET THE APPARENT EFFICIENCIES. AFTER ALL, VIRGIN TNT CAN BE HAD FOR TWELVE CENTS/POUND. WE CAN SELL TNT ON THE OPEN MARKET FOR MORE THAN THIS IF WE OFFER IT IN A PROPER FASHION TO INDUSTRY. WE CAN EAT UP ANY ECONOMICS IN TRANSPORTATION AND HANDLING. THE SAME IS TRUE IN MANY OTHER AREAS. THESE LAST VIEWS ON RECYCLE ARE MY OWN AND ALLOW ME TO CLOSE ON A MILDLY CONTROVERSIAL NOTE. ARE THERE ANY QUESTIONS?

JOINT PANEL OBJECTIVES

DEVELOP

- A JOINT PLAN TO SUPPORT CONTINUING R&D AIMED AT DETERMINING ECONOMICAL, CLEAN MEANS TO DISPOSE OF AMMUNITION ASHORE

DEFINE

- JOINT APPLICABILITY OF DISPOSAL REQUIREMENTS

INSURE

- THAT DISPOSAL FACILITIES ARE SHARED

PROVIDE

- A PLAN FOR DISPOSAL OF CURRENT INVENTORY OF EXCESS AND OBSOLETE MUNITIONS

SUBMIT

- FINAL REPORT MARCH 1973

AMMUNITION DISPOSAL REQUIREMENTS

	CURRENT TONS (THOUSANDS)	FUTURE* TONS (THOUSANDS)
ARMY CONUS	54.6	224.3
ARMY OCONUS	4.3	—
NAVY CONUS	121.1	209.1
NAVY OCONUS	.7	—
AIR FORCE OCONUS	.3	—

* 5 YEARS TOTAL

FAMILY CODE SYSTEM

P	15	A D C
FAMILY	TYPE	METHODS
SMALL ARMS AMMUNITION	20MM	A. INCINERATION D. OPEN BURNING C. DEMOLITION

DISPOSAL TECHNIQUES

DETONATION

OPEN BURNING

CONTROLLED INCINERATION

WASHOUT

DISASSEMBLY

RECOVER MATERIALS

PROVIDE ACCESS

ISOLATE HAZARDOUS COMPONENTS

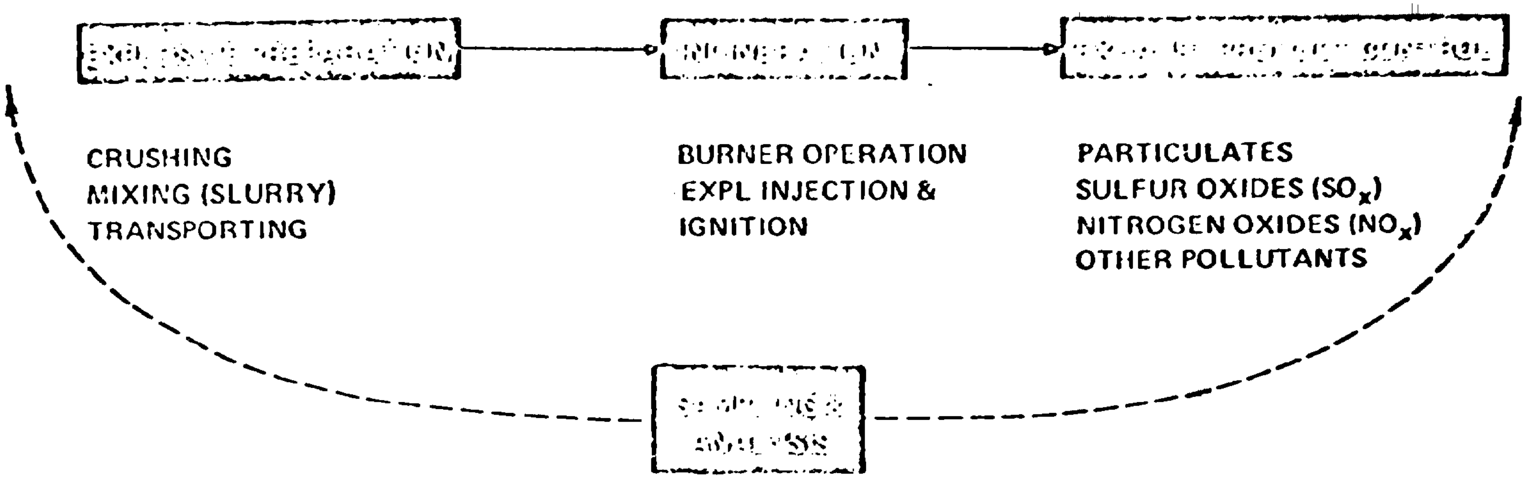
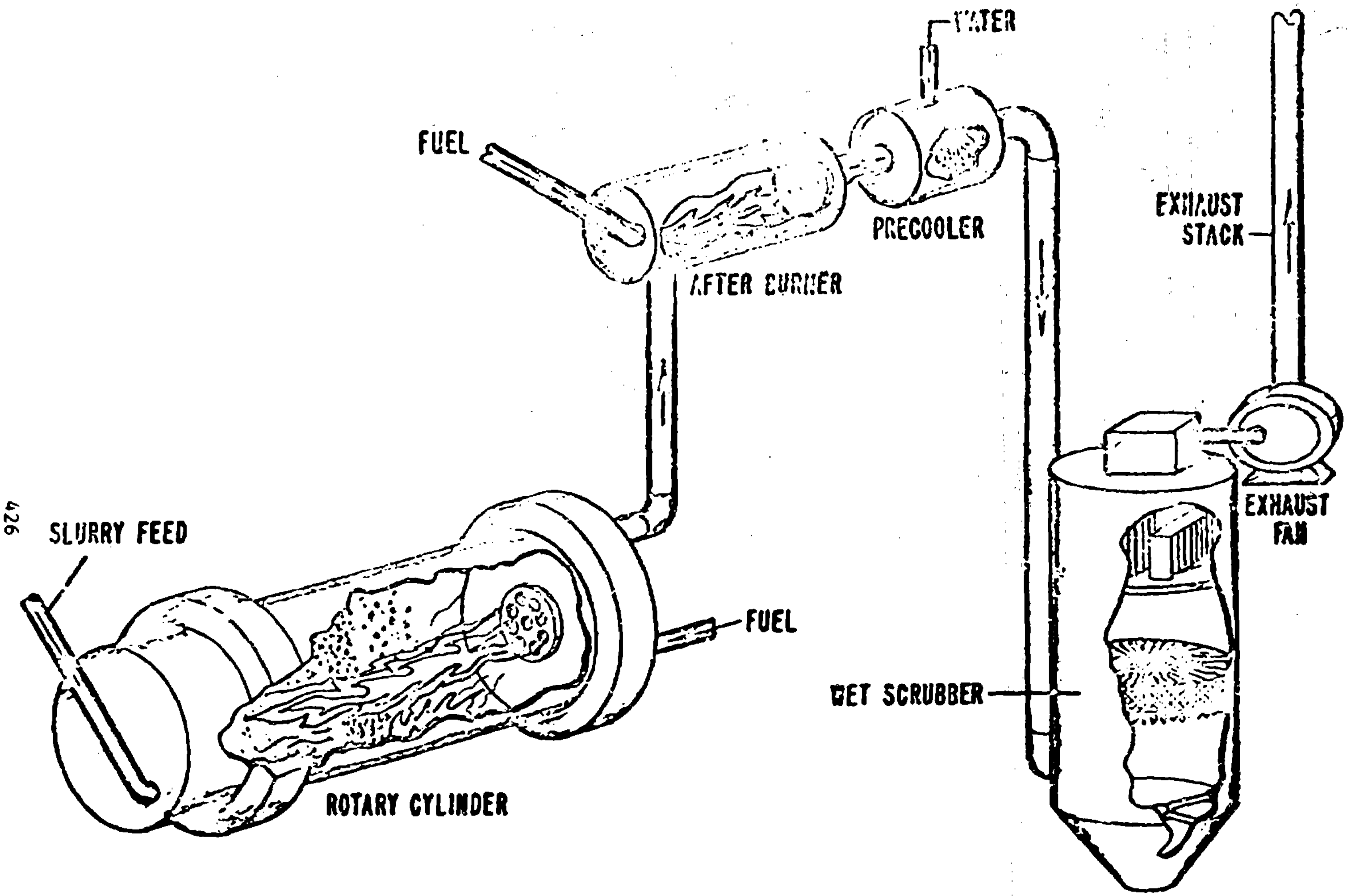


FIG 6 EXPLOSIVE WASTE INCINERATION AS A SYSTEM



ROTARY KILN INCINERATOR SYSTEM
FIG 3

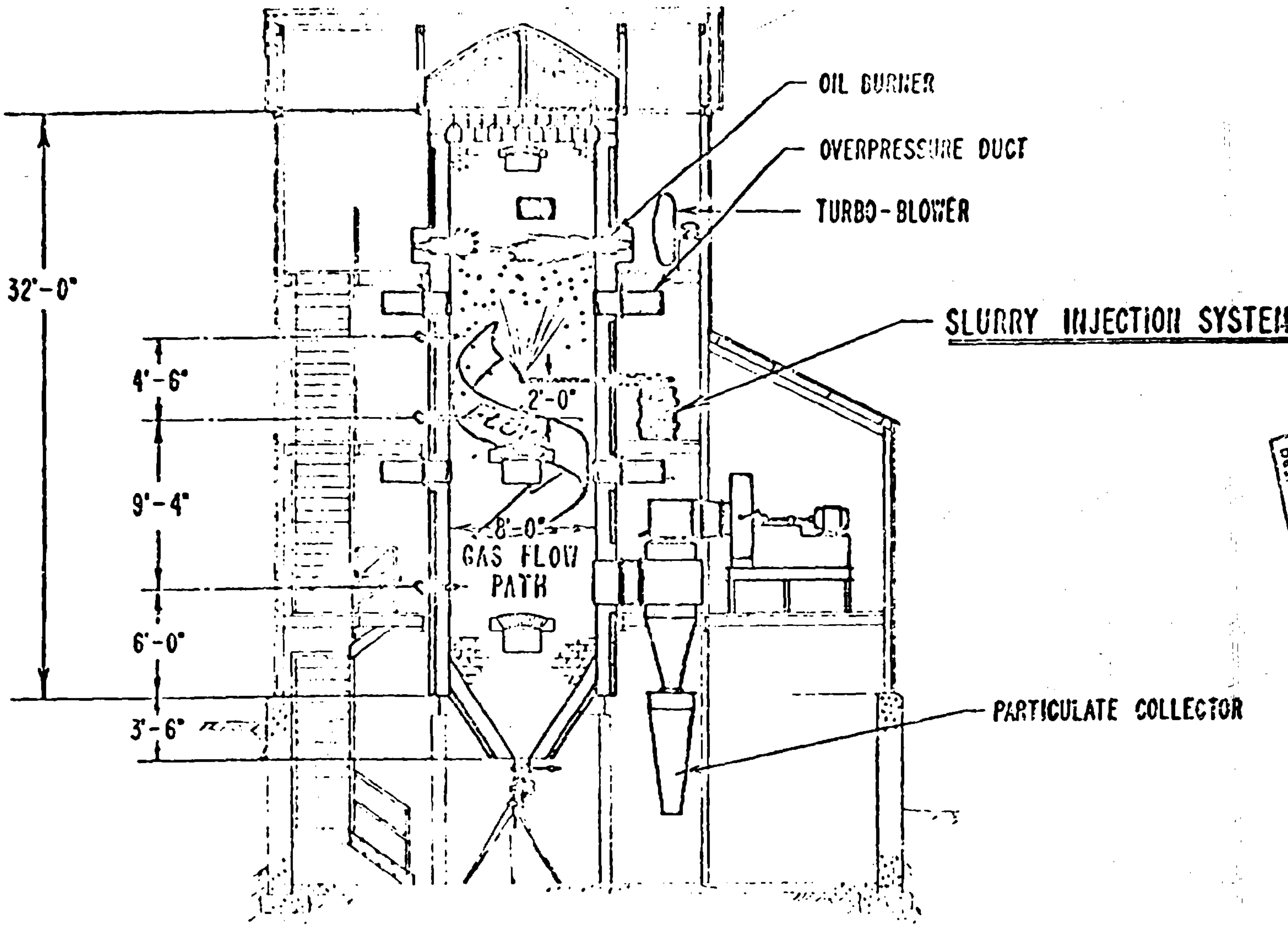


FIG 7 PICATINNY ARSENAL-VERTICAL INDUCED DRAFT INCINERATOR

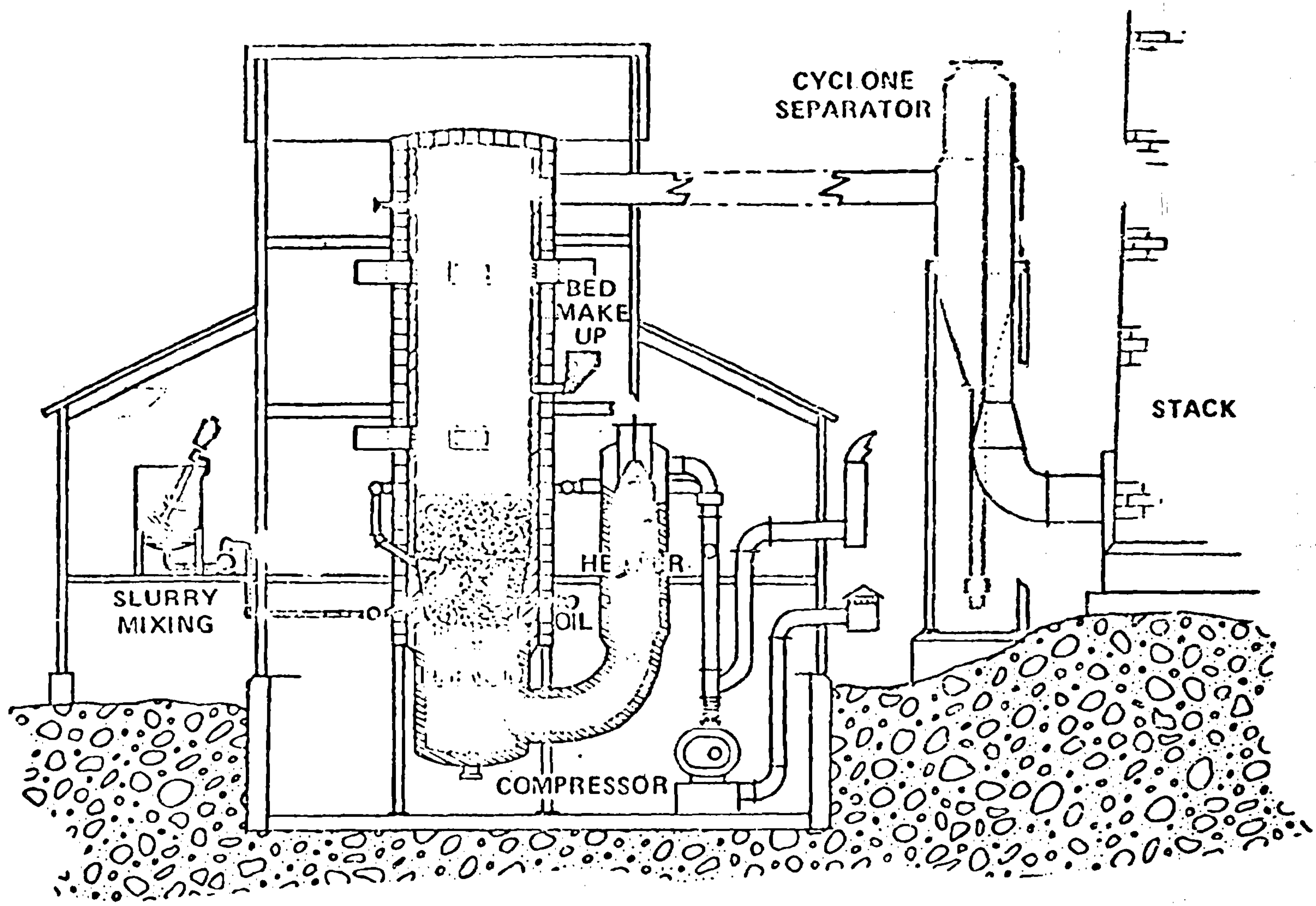


FIG 8 FLUIDIZED BED CONVERSION
PA INCINERATOR

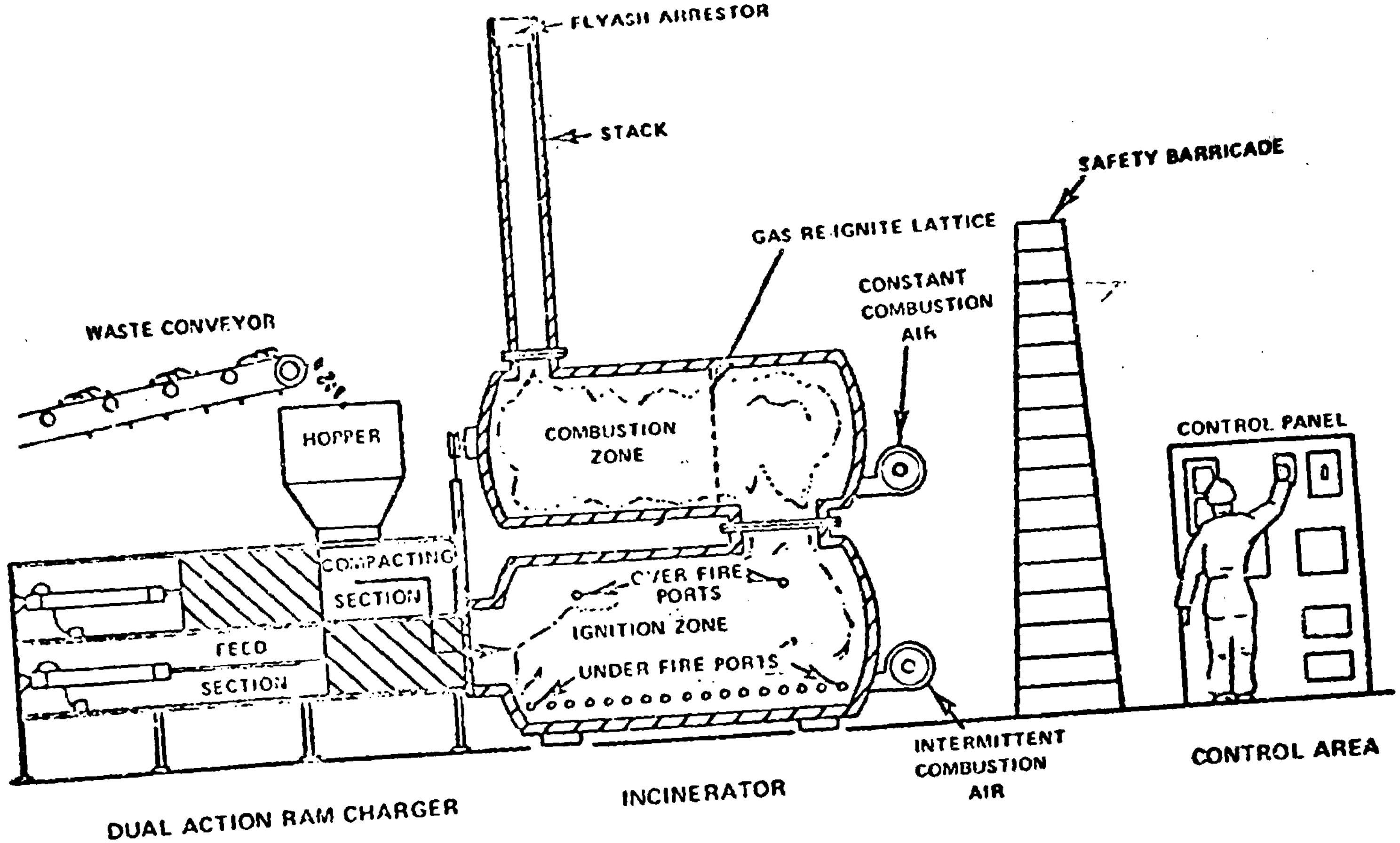


FIG 9 CONTAMINATED INERT WASTE INCINERATOR

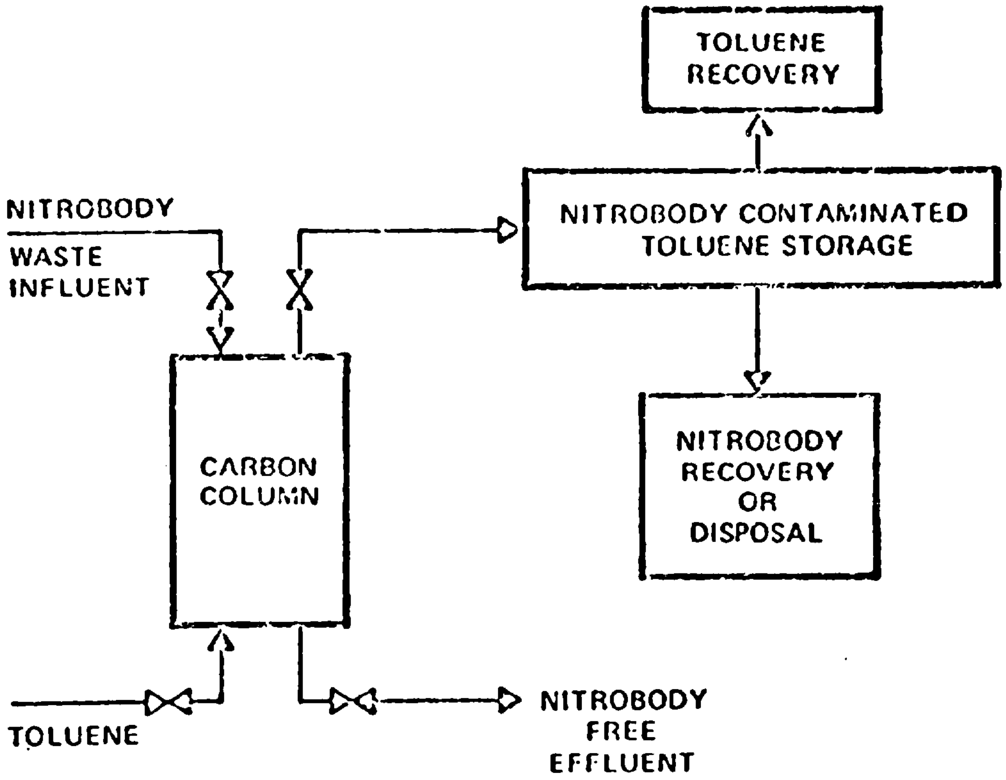


FIG 5 CARBON ADSORPTION
SOLVENT REGENERATION

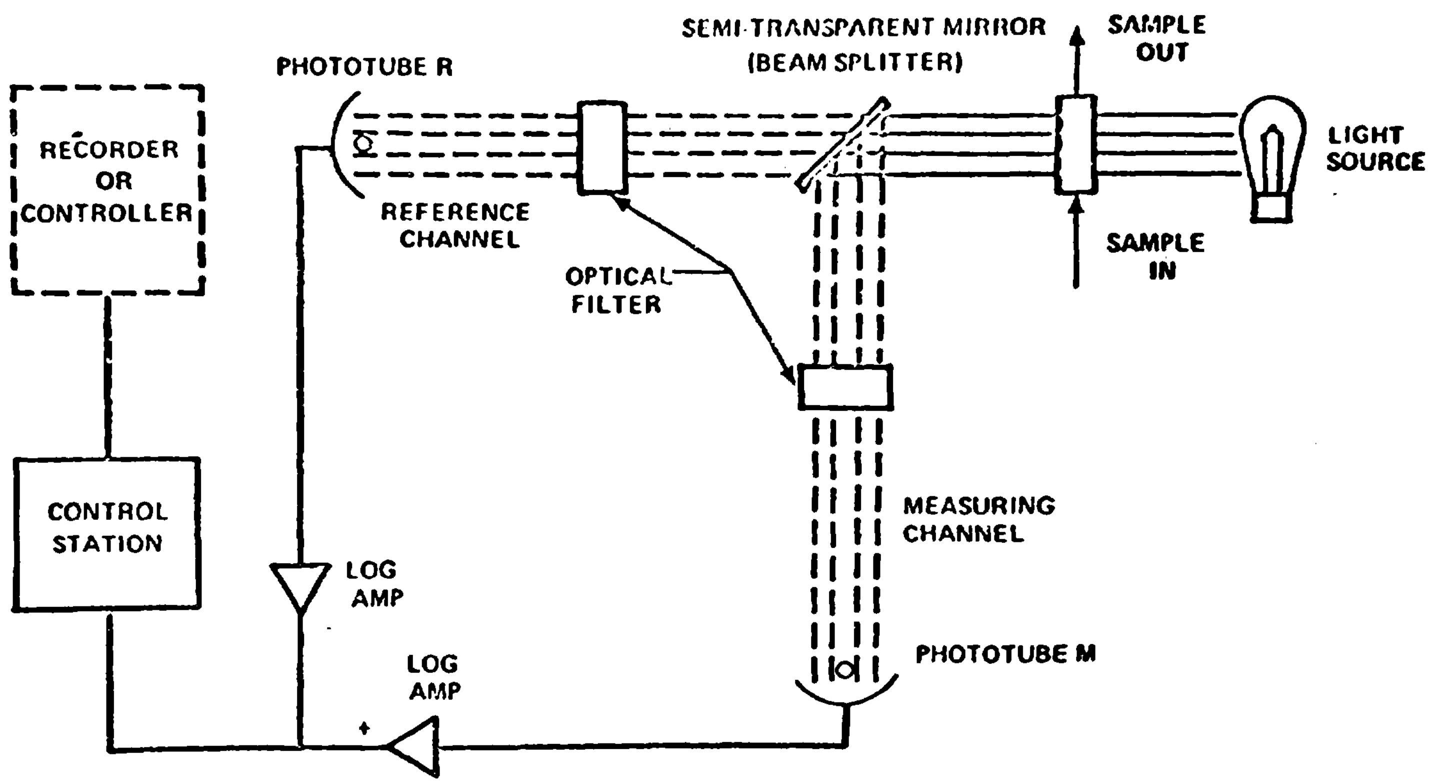


FIG 10 PINK WATER ANALYZER

TEST AND EVALUATION OF EXPLOSIVE ITEMS WITH IONIZING RADIATION AND OTHER NONDESTRUCTIVE TEST METHODS

Howard Heffan
Quality Evaluation & Engineering Laboratory
U.S. Naval Weapons Station
Concord, Calif.

ABSTRACT

The need for complex, critical, and safe explosive devices and assemblies with high reliability, has led over the years to the continuous development and application of improved inspections and tests of the material. In addition to proof firings and other destructive tests that are necessary for all aspects of explosives use, there has been an increased incorporation of nondestructive testing (N D T) into design, manufacture, quality assurance, and other programs. As a result, today N D T is applied to explosive materials during manufacture, after rework, during storage, after incidents, and at other times of the life of the material. N D T is used to determine the material soundness and to provide a basis for a reliability judgement; it is also used to assure that assemblies meet safety requirements, and to assist in determining the cause of malfunction and failure.

This paper outlines the X-, Gamma-, and Neutron-Radiography, Ultrasonic Test, Magnetic Particle Test, Eddy Current Test, and some other Nondestructive Test methods that are used with explosive assemblies. Applications of the tests to detonators, pyrotechnic devices, warheads, projectiles, solid propellant grains, and other devices are described. Some general and specific safety requirements in the use of the test are presented. Overall, the application of nondestructive tests to explosive has been effective and worthwhile, and the paper concludes that increased utilization of the existing test methods and continued development and application of new methods are to be expected.

INTRODUCTION

A nondestructive test is an examination, inspection, or test that is applied to components and materials to obtain specific information about the soundness and other properties without damaging the material to the degree that would make it unfit for service. Nondestructive Testing (N D T) of explosive ordnance materials is certainly not new. Explosives and fuzes were radiographed as far back as World War I, and by one method or other N D T has been used on ordnance materials in one form or other ever since. The applications listed in Table 1 are just a few examples of that use, and shows the extent to which N D T methods serve the explosive ordnance field.

In addition to the presentation of how the application of N D T improves the overall serviceability and safety of explosive ordnance materials by screening out the defective and substandard components, this report also answers the important question of which N D T methods are safe to apply, and which methods must be applied with caution.

Table 1

APPLICATIONS OF N D T TO
EXPLOSIVE ORDNANCE

X-Ray and Gamma-Ray Radiography

Rocket motors for soundness of grain and peripheral bonds, effects of aging, handling, etc.
Warheads for soundness and effects of aging.
Fuzes for soundness, proper assembly, arming.
Detonators, primers, & Squibs for soundness and proper assembly.
Projectiles for soundness of charge, including gaps and an indication of explosive density.
Bombs for soundness and proper assembly.
Mines and Depth Charges for soundness and proper assembly.
Torpedos for soundness and proper assembly.

Neutron Radiography

Detonators, squibs, etc. for soundness and density of explosive charge.
Explosive cords for soundness.

Ultrasonic Testing

Rocket motors for case inspection, liner thickness measurements, and quality of adhesive bonds.
Warhead for soundness of metal parts.
Fuzes for soundness of metal parts.
Projectiles for soundness of metal case.
Bombs for soundness of metal parts.
Mines and depth charges for the soundness of metal parts.
Torpedos for the soundness of metal parts.
Cartridges for soundness of metal case.

Eddy Current Testing

Cartridge cases for hardness and metallurgical properties.
Explosive cords for the thickness of the metal jacket.
Projectiles for cracks in case.

Magnetic Particle Testing

Rocket motor for soundness of the (steel) motor case.
Warheads for the soundness of the (steel) case.

X-RAY AND GAMMA-RAY RADIOGRAPHY

Radiography with X-ray and gamma-ray sources is one of the most widely used nondestructive tests for explosive ordnance materials, and it is likely that at some time in the life cycle of an item, samples will be radiographed. Radiation sources cover the range of energies from about 20 KV* to 25 MEV*. Selection of the particular energy for the source depends on the thickness, density, and atomic number of the material. In this method the radiation from the source is made to pass through the object and impinge on a sheet of X-ray film. Voids, gaps, inclusions, internal arrangements, and many other conditions of the material cause differential absorption of the radiation as it passes through the object and causes an image to form on the film. Interpretation by a film reader is the last step in the procedure.

The formation of the image on the X-ray film is a distinct advantage of the radiography method. Optimum sensitivity can be achieved in practically every application, and multiple images can be obtained at many angles through the object to allow for a more thoughtful interpretation, if required. The equipment is versatile, and the method is easily applied; special preparation of the objects is not needed normally. Associated with its long history of development and use are the standards and standardized practices that have been initiated and permit results that are expected to be obtained.

Disadvantages of the method are that a facility with thick shielding walls, to protect personnel from the radiation are required. Time is needed to make the exposure and develop the film; interpretation of the resulting radiograph needs the services of an experienced film interpreter. Also, with the normal procedure of taking only one radiograph of a part, the image of faults and defects may not be the best, and interpretation may be limited.

*KV = Kilovolts (1,000 volts)
**MEV = Megavolts (1,000,000 volts)

RADIOGRAPHY
SAFETY SUMMARY

1. The amount of radiation absorbed by explosive ordnance material is extremely small, and well below the levels that could produce damage, even in the most sensitive materials, such as plastics that contain fluorine.

2. High voltage electric equipment is involved with X-ray sources, and therefore, grounding, shielding, and other electrical protection procedures must be employed. This is not a problem with the use of radioactive isotope gamma-ray sources.

3. No special handling of explosive materials are required in a radiography facility. Only in rare and special cases is it necessary to open a sealed explosive assembly, and work in contact with the explosive (usually solid propellant). That work must [illegible] the established rules; radiography [illegible] additional requirements.

APPLICATIONS

20 MM Ammunition

Investigations into the causes of premature detonations and breakup during test firings in new lots of 20 MM ammunition showed that radiography would segregate an average of about 4% with misassembled and otherwise substandard rounds. Test firings showed no malfunctions in rounds found acceptable by X-ray examination, and premature detonations and other malfunctions were related to various defective and deviate conditions shown by radiography. Radiography has been used on over a million rounds from production lots of all types, for quality control and on a sampling basis in lot acceptance tests and surveillance. Figure 1 shows the appearance on the X-ray film of six types of 20 MM ammunitions.

PRIMERS AND FUZES

Misassembled fuzes and primers periodically appear in stock supply, as a result of malfunctions, and in new production. Radiography is now a standard procedure to screen lot of fuzes and primers of defective and substandard material. Figure 2A shows the appearance of a 250 KV X-ray radiograph of a projectile auxiliary detonating fuze and the images of the internal assemblies.

TORPEDO SECTIONS

Structural failures of torpedo sections during test runs resulted in radiography being applied to determine the causes of failure, and to provide the quality control and assurance in subsequent production. In one case, radiography and metallurgical examinations revealed a complete loss of control of the welding procedure, with resulting lack of penetration of the weld into the roots of the welded joints. Acceptance standards were developed from prototype units that passed all development testing, and all production now requires this radiography. Figure 3 shows the arrangement for radiography of the torpedo section joints.

MEDIUM CALIBER GUN AMMUNITION

The great intensity of shore bombardment by Naval guns in Southeast Asia resulted in production problems that were not previously encountered. These problems resulted in the establishment and application of radiography and ultrasonic tests (see following section) to new and segregated material to screen out those with faulty construction. This work is still in progress and has clearly raised the quality level of the ammunition supplied to the fleet. Figure 4 shows a 400 KV X-ray unit at a Weapons Station arranged to radiograph a 5-inch projectile.

MISSILE WARHEADS, BOMBS, AND DEPTH CHARGES

Warheads, bombs, and depth charges in storage are periodically sampled and subjected to surveillance testing. This testing program regularly incorporates a complete radiographic examination to detect deterioration due to ship board handling and depot storage. Also, on ocassion, it becomes necessary to examine samples of these explosive loaded items because of production, test, or service related problems. Radiography has proved invaluable in identifying the internal conditions that caused the problem, and to indicate the way for corrections. These items with cast explosives exhibit in varying degrees the porosity, cracking, cavitation, and other defects that are characteristic of the cast material. Figure 5 shows the 2 MEV X-ray source in position to radiograph depth charges. Figure 6 shows the appearance of severe cavitation in a 250 lb. bomb on the radiograph. It exceeds the allowable limit and is cause for rejecting the bomb. Figure 7 shows the 7.5 MEV Linear accelerator X-ray source in position to radiograph a missile warhead.

SOLID PROPELLANT ROCKET MOTORS

As a class of ordnance material, solid propellant missile motors probably receive more radiography than any other. Radiographs are made of new motors, periodically during storage, and after return from issue to the ships. In general, two areas of the motors must be examined; these are the solid propellant grain, and the peripheral adhesively bonded areas. Acceptance standards have been developed for all missiles, of propellant grain defects, and of separations in the case and insulation bonds. Some procedures require upwards of 100 exposures and the production of several hundreds of film for the complete examination. In terms

of numbers of people, costs, and investment in facilities and equipment, this work may exceed all other testing. Figures 8 through 13 show the variety of applications that are in progress.

FLASH X-RAY

A unique radiographic technique that is ocassionally needed to examine explosive ordnance used pulsed X-ray from a pulsed source. An application that is now in progress involves radiographing medium caliber projectiles after they leave the cannon during a special test firing. Figure 14 shows that 2 MEV pulsed source for flash X-ray work. By changing the tube, this unit can be used for electron irridiation studies for electronic component reliability.

NEUTRON RADIOGRAPHY

Aware of the limitations of X-ray radiography for examining explosives contained in metal jackets such as in detonators, squibbs, etc.; radiographers have recently looked toward and made effective, use of neutron beams. In neutron radiography which is performed at this time at established nuclear reactor locations, the neutrons produce images of defects in the explosive cavity and this work has greatly improved the reliability of these devices. Figure 2B shows a neutron radiograph of a projectile auxiliary detonating fuze, and shows the explosive train and other parts not as readily imaged in the X-ray radiograph. Figure 15 shows neutron radiographs of detonators and the appearance of the defects and substandard qualities that can be produced.

ULTRASONIC TESTING

Except for recent research with ultrasonic imaging and ultrasonic holography (discussed in a later section), ultrasonic testing of explosive ordnance is exclusively applied to the metal and other inert parts. In this test, which employs pulses of very short duration, ultrasonic energy from a transducer is transmitted into the metal surface through a thin liquid fiml that is applied to the surface, called the couplant. The sound pulses pass through the material and will echo from surfaces of internal cracks, voids, gaps, unbonds, etc. A receiving crystal often the same as the transmitting crystal, held to the surface detects the received pulses, and passes them to the test instrument for display.

Ultrasonic testing can be performed with access to one side of a part; this is an advantage. Also, there is an immediate response and indication of the test result. Relatively little equipment is required for the ultrasonic test, and this method can probe large thicknesses of materials. Metals and non-metals may be examined, including both solid and laminated assemblies. Application does require skilled and qualified technicians, and it can be slow to apply, especially in irregularly shaped objects that need special angulation and beaming control.

ULTRASONIC TESTING
SAFETY SUMMARY

1. Ultra ic transducers should not be placed in contact with exposed explosives or propellants.

2. Where the ultrasonic test procedure applies to the examination of metal and other inert parts containing explosives, there is no hazard from the minute amount of ultrasonic energy that may enter the explosive or propellant materials, and the test may be applied without special precautions.

3. High voltage electronic equipment is involved in ultrasonic testing; the voltage in the cable to the transducer can reach values of between 500 and 1500 volts. Good grounding and other electrical protection practices should be followed.

4. Care should be taken in the selection and application of the liquid couplant to avoid possible contamination and accidental entry of the couplant into the explosive cavity.

APPLICATION

Integrity of BULLPUP Missile Warhead Assembly Joints

Breakup of some BULLPUP missiles during flight resulted in the discovery of defective spot welds in the joints that fold the missile sections together. An ultrasonic test procedure and acceptance standards were developed for the inspection of the warheads. A sampling of the stock supply showed that a large number of the warheads contained joints with many defective welds, and a complete renovation program was begun to bring the warheads in the stockpile up to standard. Figure 16 shows the application of the manual, ultrasonic test procedure; the use of battery operated instruments permitted this test to be used inside magazines. Figure 17 shows the ultrasonic screen patterns for good and bad welds.

Case-to-insulation Bond of Large Solid Propellant Rocket Motors

Ultrasonic tests are widely used to examine the adhesive bond between the case and the insulation of solid propellant rocket motors. In this test the operator applies the ultrasonic transducer to the outside of case and scans the surface for indications of separations. Ultrasonic energy that enters the case and insulation is greatly attenuated, and little or no energy reaches the propellant. Figure 18 shows the performance of this test.

Base Detonating Fuze of 5-Inch Projectiles

After a breakdown and detailed inspection of 5-inch projectiles from a lot that was suspended because of a premature detonation during firing, it was found that some of the base fuzes had their inside locking pin drilled hole in line with one of the two outside spanner wrench drilled holes. With the two holes lined up that way, there is a possibility that the base metal between the holes may be extremely thin, or that the holes may penetrate the metal completely, and allow the propellant gases to enter the fuze during firing. An ultrasonic test procedure was developed that uses a special angle (wedge) adapter applied to the outside, base surface of the projectile, to locate the position of the inside drilled hole. The test procedure indicates the hole location to the

operator, and if it is in close proximity to one of the outside spanner holes, the operator segregates the round. Operators were trained and the procedure was applied to all of the 5-inch projectiles in the Navy's stock, both here and at overseas bases. Figure 19 shows an operator applying the test with the ultrasonic adapter held to the base of a projectile.

SIDEWINDER Missile Warhead Examination

Investigation of in-flight breakup of SIDEWINDER missiles revealed that the Warhead structural integrity can be significantly reduced and that case areas that support coupling attachment can contain fatigue cracks and other critical defects. An immersed ultrasonic test was developed to detect cracked or substandard warhead, and were applied to screen the stocks. Figure 20 shows the test system that was assembled for this work.

5-inch Projectile Bodies

Newly forged steel projectile bodies were found with critical forging defects, that resulted in projectile body splitting during the pressing operation of loading. Others that withstood the loading pressures were placed in storage and service. An immersed ultrasonic test procedure was developed to examine the new projectile bodies, and a contact procedure was used to examine loaded projectiles from storage. Figure 21 shows the test system assembled for the automatic ultrasonic test of projectiles in the loading plants. Eight such units were placed in operation for screening the bodies prior to loading. Three high speed units were built to replace these slower units, and are still in operation at the depots.

EDDY CURRENT TESTING

Metal parts are examined by the eddy current test method by bringing them into the electromagnetic field of a coil in which alternating current is flowing, and noting the response in the electronic circuit to which the coil is connected. In the test, electric (eddy) currents are induced into the metal with a magnitude and phase relationship that is affected by the size and shape of the test piece, and on the chemical, physical, metallurgical, and soundness characteristic of the metal. Since the response is sensitive to the electrical conductivity of the metal, this test is used as a method of sorting metals. The extreme sensitivity to the distance of the probe coil to the metal surface is the basis of using this technique to measure coating thicknesses. The modifying effect of cracks and flaws in the metal on the induced eddy currents permits the method to be used for soundness determinations. For magnetic steel, similar tests rely on the magnetic and electrical properties of the metal.

Eddy current testing and magnetic indication testing are simple and fast; they consist of inserting the part in the test coil, and observing the indication on the test instrument. Instrumentation can be small, and portable; the wide choice of frequency for the driving field to the coil make the test very versatile, and special electronic processing has made the test applicable to a wide range of metal inspection problems. Since each of several conditions of a metal part can cause a response in the instrument, this multiple sensitivity can confuse the test where controls on each variable are not maintained. As in ultrasonic testing, application of eddy current testing requires a trained and qualified operator.

EDDY CURRENT TESTING SAFETY SUMMARY
Since eddy current tests apply only to the metal parts of an explosive assembly, direct application of the test to explosive materials is not made. In use, normal electrical grounding and R F protection practices should be enforced.

APPLICATIONS

STEEL AND BRASS CARTRIDGE CASES

Cartridge cases, both brass and steel have properties that make them suitable materials for the application of eddy current and magnetic indication tests. Because the energy of these tests penetrates only the metal, they may be applied safety to loaded cartridge cases. Brass cases have been susceptible to stress corrosion cracking, when their hardness and metallurgical properties are out-of-spec. The application of an eddy current test can readily segregate the deviate material, and can preclude the necessity to perform the mercurous nitrate strain test, with all of its problems. Steel cases offer a similar opportunity to detect out-of-spec and substandard material. For this, a magnetic induction test can be applied to provide a quantitative correlation for such properties as hardness, coating thickness, and soundness. Figure 22 shows the test applied to 5-inch steel cases to detect soft spots and improperly heat treated cases. The test can be automated and performed at high speed.

MAGNETIC PARTICLE TESTING

In this test, a magnetic field is set up in the steel by means of a permanent or electromagnetic, or by passing A. C. or D. C. through the part. Magnetic poles are formed at cracks and other discontinuities where the field leaves the metal. Small iron oxide particles that are sprinkled over the surface during or immediately after magnetization become attracted to the poles and thus indicate the crack. The magnetic particle test is useful for detecting surface and near surface cracks and other discontinuities in ferromagnetic steel parts. It is fast and relatively easy to apply, and much of the equipment is portable and inexpensive. Clean surfaces are needed, and if fluorescent magnetic particles are to be used, a darkened room and an ultraviolet "Black Light" are needed.

MAGNETIC PARTICLE TEST
SAFETY SUMMARY

1. Magnetization of explosively loaded ordnance should be accomplished with a permanent magnetic, or a low-voltage, low current electromagnet. Electromagnet windings should be insulated and the test system grounded.

2. The test may be performed with igniters, detonators, squibs, etc. installed if good shielding and grounding are accomplished and provided the inspection avoids the areas where these devices are installed.

3. Demagnetization of the part tested should be accomplished by stepped reductions of an A. C. electromagnet.

ASROC MOTOR CHAMBERS

After storage and fleet environment, cracks appeared in the fillet welds attaching the fin attachment bases to the aft end of the ASROC motor chamber. Corrosion was also observed. A magnetic particle test technique was developed to examine all of the loaded motors in stock. The procedure uses a low voltage, low current D. C. electromagnetic yoke, that is placed in contact with two adjacent base plates. The magnetic field produced by the yoke passes through the two bases and their attachment welds. A dry powder is sprinkled over the areas, and a buildup of the powder indicates the crack. Figure 23A shows a motor case with severe corrosion under the attachment base. Figure 23B shows visual and ultrasonic patterns of a corroded area. Figure 24 shows the magnetic particle indication of cracks in the attachment welds.

INFRARED (THERMAL) TESTING

The infrared (detection & imaging) test is a non-contact thermal test, where infrared radiation from a warm object is picked up by sensors for processing and display. Although the best results are obtained at temperatures above 200°F (100°C), effective tests have been performed at lower temperatures. The infrared, as do other thermal tests, depends on thermal gradients forming in an object, whose magnitude and distribution are related to the presence of discontinuities, laminations, unbonds, etc. within the part. Objects such as energized resistors, and other electrical components develop a heat pattern during normal operation, and may be examined during operation for the presence of the "heat signature". Objects such as explosive loaded ordnance items that are normally stored at ambient temperatures do not have an inherent temperature distribution, and must be processed through a heating and cooling cycle to establish a temperature profile.

POLARIS Missile Motor Application

An infrared system was developed that included a detector and signal processing system for detecting peripheral unbonds in the POLARIS motor. The system was demonstrated to have sensitivity to the range of conditions of interest, however, to function, it was necessary to heat the motor in an oven at 110°F or more. Figure 25 shows an infrared scanning camera arranged to examine a POLARIS motor removed from a soaking oven. This was considered undesirable, and the system was not used. With the availability of new high speed and very sensitive infrared cameras, it may be possible to perform the examinations of solid propellant motors at near ambient temperatures, and there is current interest in the potential applicability of this method.

FLUID PENETRANT TEST

This test consists of soaking the surfaces of a part in a penetrating oil containing soluble dyes for a sufficient time to ensure penetration of the oil into cracks and other openings. The surfaces are then cleaned to remove excess oil from the surfaces, but in a manner that leaves the penetrant in the cracks. A developer is then applied to enhance the indication by drawing the oil out of the crack through capillary action. With the visible dye, inspection is made in the light; with the fluorescent oil, the part must be viewed under the "black" light.

The method is simple to use, and can be applied to large and small parts. Since the penetrant may pass through very small openings, care must be exercised with explosive loaded assemblies to prevent leakage of the penetrating oil into the explosive cavity.

APPLICATIONS

The penetrant test is applied in general to metal and plastic parts to detect cracks, porosity, separations, and leaks. It has been used successfully to inspect corroded areas in missile assemblies, and to examine cartridge cases suspected of stress corrosion cracking.

VIBRATION (MECHANICAL IMPEDANCE) TESTS

Testing materials with mechanical vibration depends on the ability of the material to support the vibrational energy. In the simple "Tap" test for case bonding of a solid propellant missile motor, the sound of the "tap" can be related to certain unbonds. In more sophisticated systems that use vibration, sensors are attached to the critical points on the system, and the response to the forced vibrations are measured and analyzed. Incorporating a system of optical holography with a vibration test offers the possibility of detecting very small deviations from normal.

R F, ELECTRICAL, & ELECTRO-THERMAL TESTS

Testing electrical detonators, primers, squibs, and other electroexplosive devices (EED) for soundness and reliability of the electrical bridgewire circuit is a complex problem. For

devices that do not contain "safing" gaps in the conductors, small pulsed and controlled currents, A. C. or D. C., can be used, with studies of the impedance and thermal effects. For devices with safing gaps, high frequency R F energy must be used with a study of the waveform of the transmitted energy. These tests, when augmented with sample destructive firing have been useful as quality control tests.

ACOUSTIC EMISSION

Considerable advances have been made recently on the development and application of acoustic monitoring during the structural tests of parts and systems. The test is based on detection of the high frequency sounds that are generated by strain and crack growth in structures that are under stress. The method has been used with hydrostatic tests of missile cases, and offers considerable promise for proof loading of air-to-air and air-to-ground missile structures.

ACOUSTIC & ULTRASONIC HOLOGRAPHY

Acoustic holography is a method of imaging the internal structure of a material by passing ultrasonic energy through the part and using an optical holographic system to form the image. In this test, the material must be immersed in a liquid for coupling the sound energy, and for the formation of the image. The method is being studied as a means of inspecting explosives and explosive loaded assemblies for flaws and density variations.

AUTOMATIC TESTING

The usefulness of nondestructive tests in flaw detection problems and in supplying information for design development and production engineering uses has been demonstrated repeatedly, and a desired automatic testing has been sought continuously. One example of development work toward that end is the Filmless Automatic Bond Inspection System (FABIS) for the examination of the peripheral bonding of large solid propellant rocket motors. The system consists of a numerically controlled programmable multiaxis drive system, that moves a collimated horizontal beam of gamma rays along the contour of a missile motor mounted on a turntable. Separations between the insulation and propellant

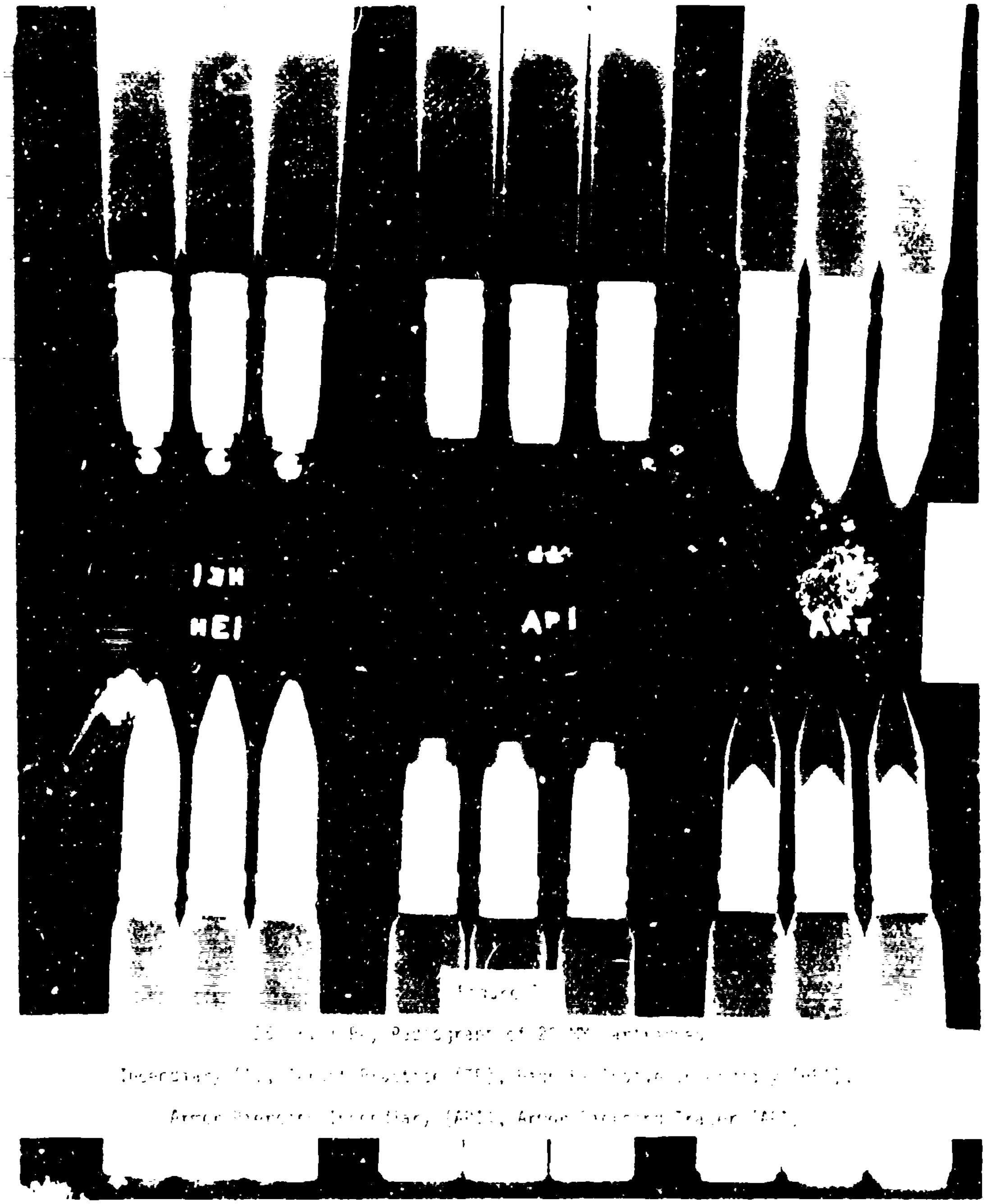
are detected by a scanning radiation detector as an increase in count rate. Defects in the peripheral propellant are also detected. Figure 25 shows the scanning equipment set up in the Naval Weapons Station, Concord facility prior to shipment to a missile motor loading facility.

N D T AT REMOTE SITES

From time to time urgent need for radiographic and other N D T capability at remote locations has presented itself. To answer these requirements, a mobile nondestructive testing laboratory was designed, equipped, and placed into operation. The mobile laboratory shown in Figure 26 consists of two van semitrailers. One contains a 75 KVA diesel-electric generator and storage space for equipment and supplies. The other van contains equipment and working space for performance of radiographic, ultrasonic, magnetic particle, and other N D T, together with automatic film processing and darkrooms. Figure 27 shows the interior working space. The vans may carry portable X-ray equipment and radioisotopes depending on the inspection problem. These vans have been used for ammunition inspection in Japan and Okinawa.

CONCLUSIONS

Because of its effectiveness and widespread acceptance in the past, and because explosive ordnance materials are and will continue to have critical requirements for serviceability and safety, it is certain that N D T methods will continue to be developed, advanced, and applied. Designers will continue to specify N D T to ensure that sound material, only, is used, and that defective material is rejected. Designs that are difficult to test will be replaced in important systems by those that are inspectable. Management will continue to support those test applications that are effective and that result in quality improvements and in cost savings. Production facilities will continue to depend upon the examinations to prevent the entry of defective material into their production lines, and to locate defects soon after they occur in production. N D T engineers will continue to improve the older techniques, and to develop the new methods as the needs arise; they will continue to study and to find the optimum test for each new problem.



[illegible]

[illegible], Photograph of 20 MM Cartridges

Incendiary [illegible], Target Practice [illegible], [illegible]

Armor Piercing Incendiary (API), Armor Piercing Tracer [illegible]

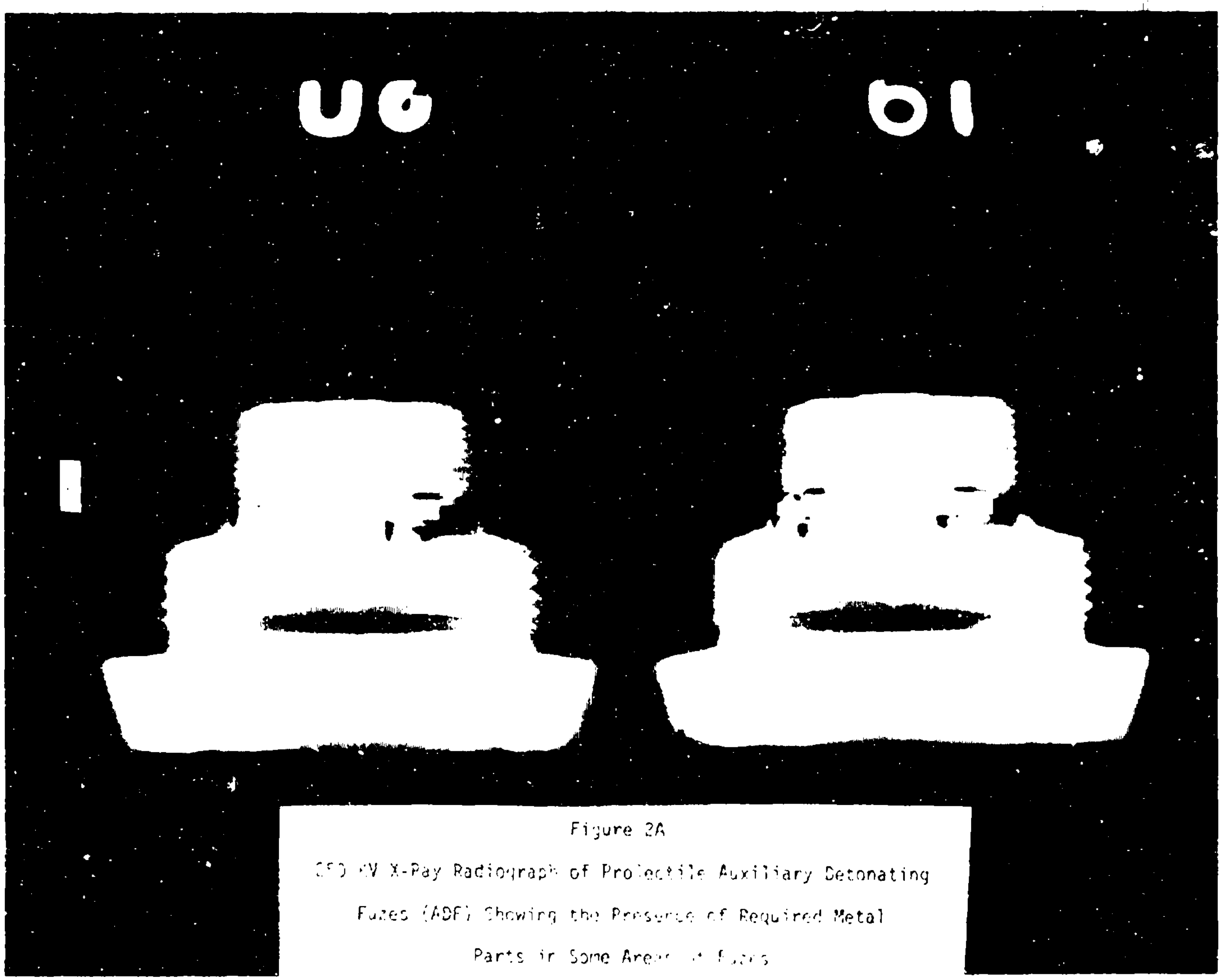


Figure 2A

250 KV X-Ray Radiograph of Projectile Auxiliary Detonating Fuzes (ADF) Showing the Presence of Required Metal Parts in Some Areas of Fuzes

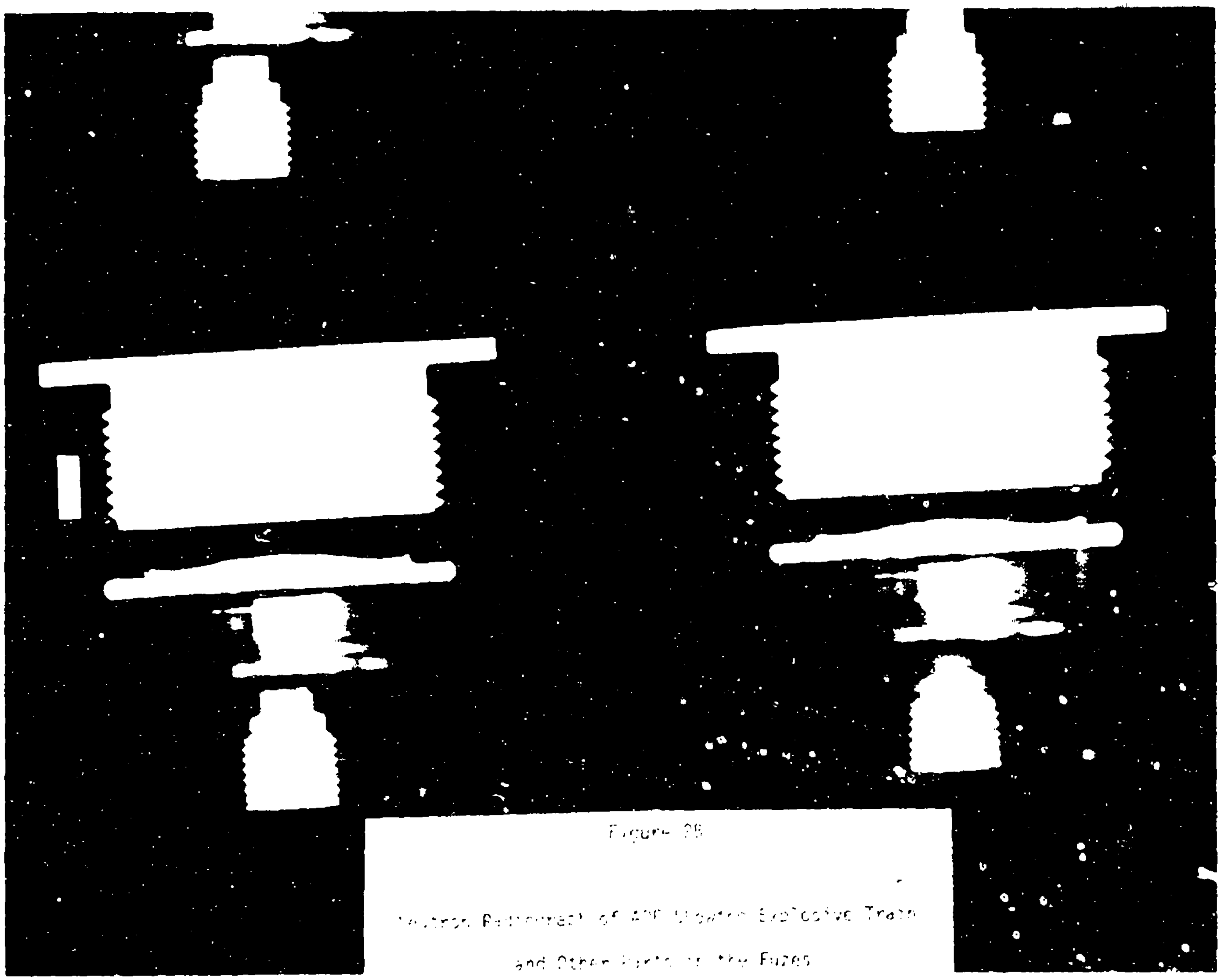


Figure 9[illegible]

Neutron Radiograph of [illegible] Showing Explosive Train and Other Parts of the Fuzes

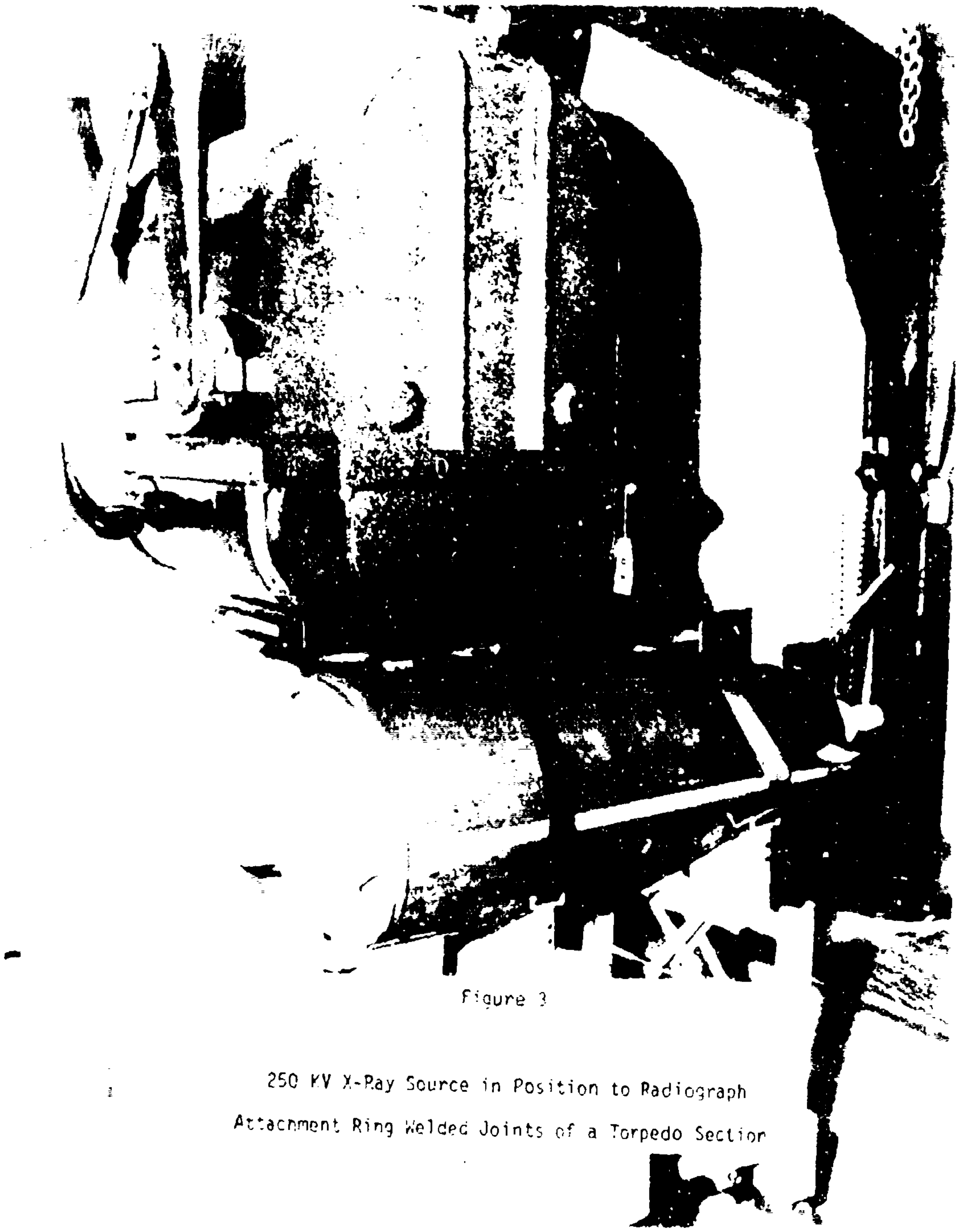


Figure 3

250 KV X-Ray Source in Position to Radiograph Attachment Ring Welded Joints of a Torpedo Section

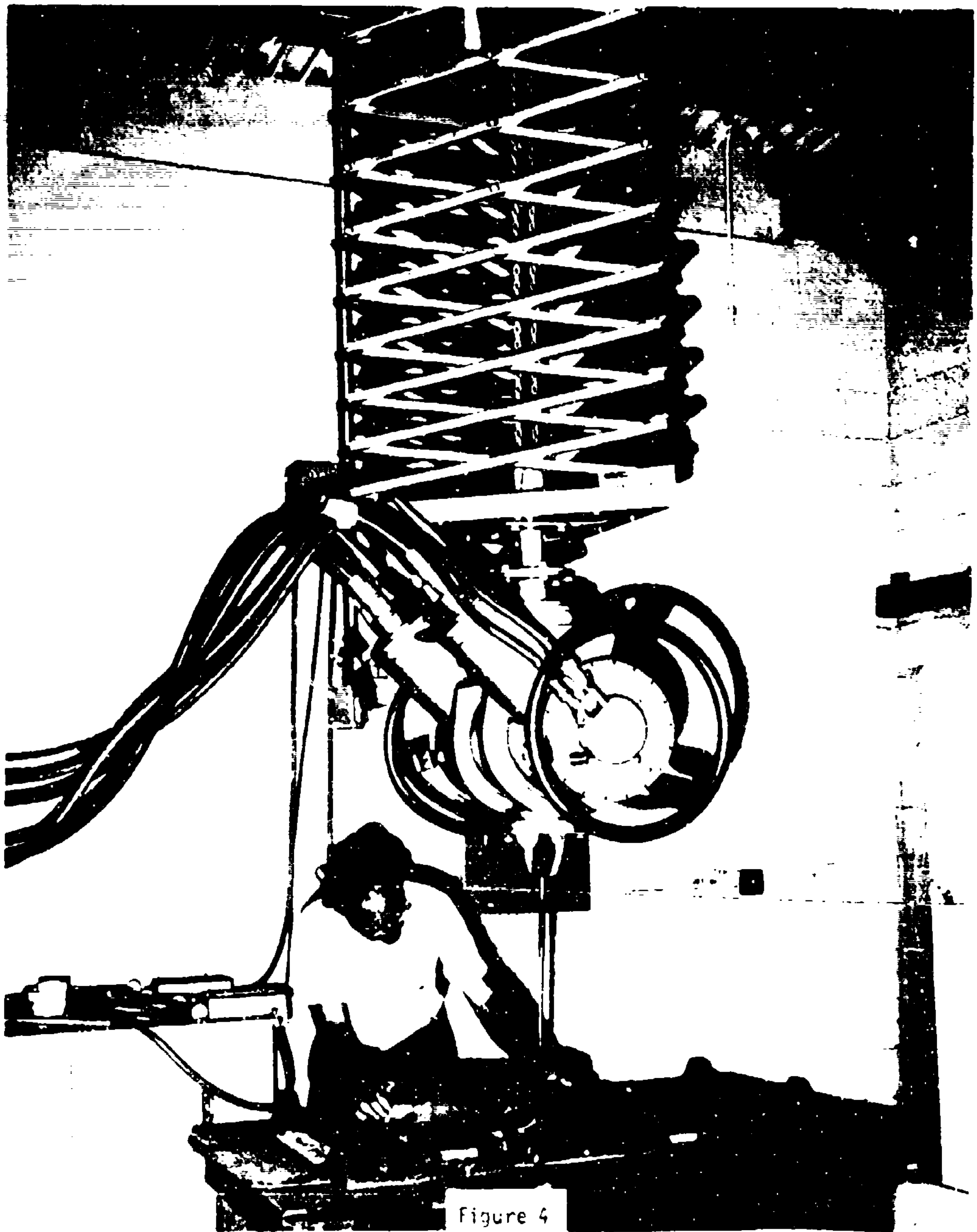


Figure 4

400 KV X-Ray Source Arranged to Radiograph a 5" Projectile

(WPNSTA Seal Beach, CA)

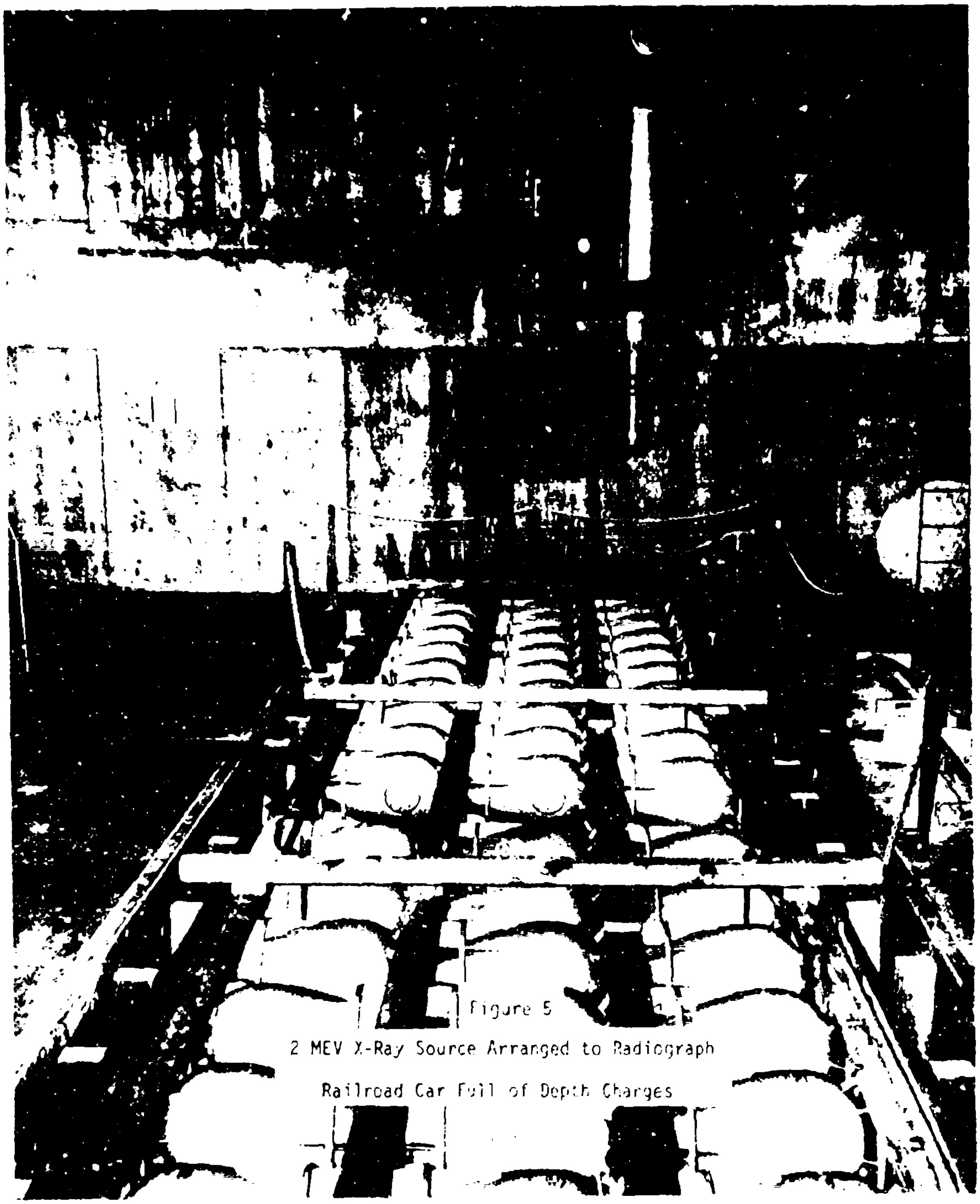


Figure 5

2 MEV X-Ray Source Arranged to Radiograph

Railroad Car Full of Depth Charges

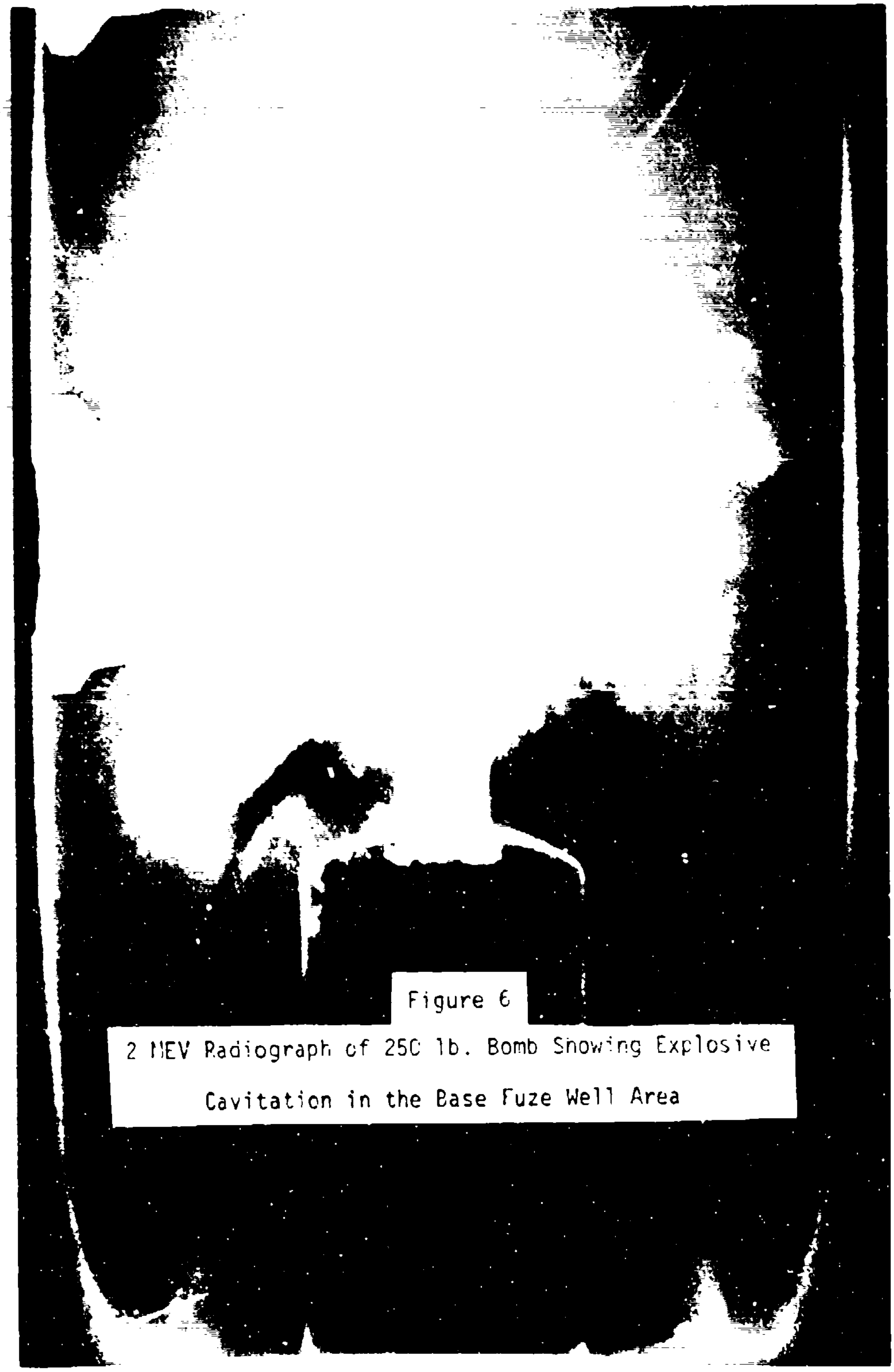


Figure 6

2 MEV Radiograph of 250 lb. Bomb Showing Explosive Cavitation in the Base Fuze Well Area

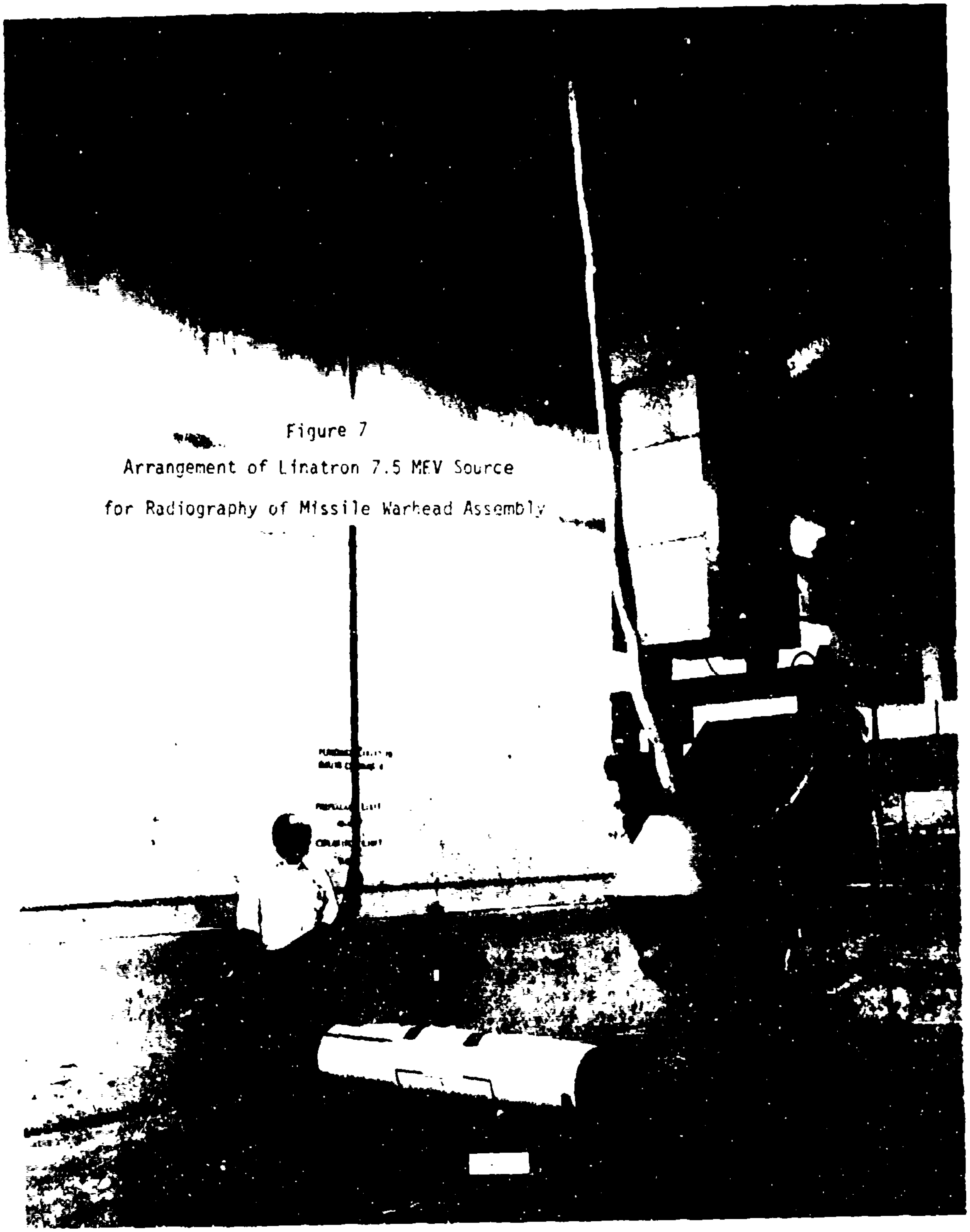


Figure 7

Arrangement of Linatron 7.5 MEV Source

for Radiography of Missile Warhead Assembly

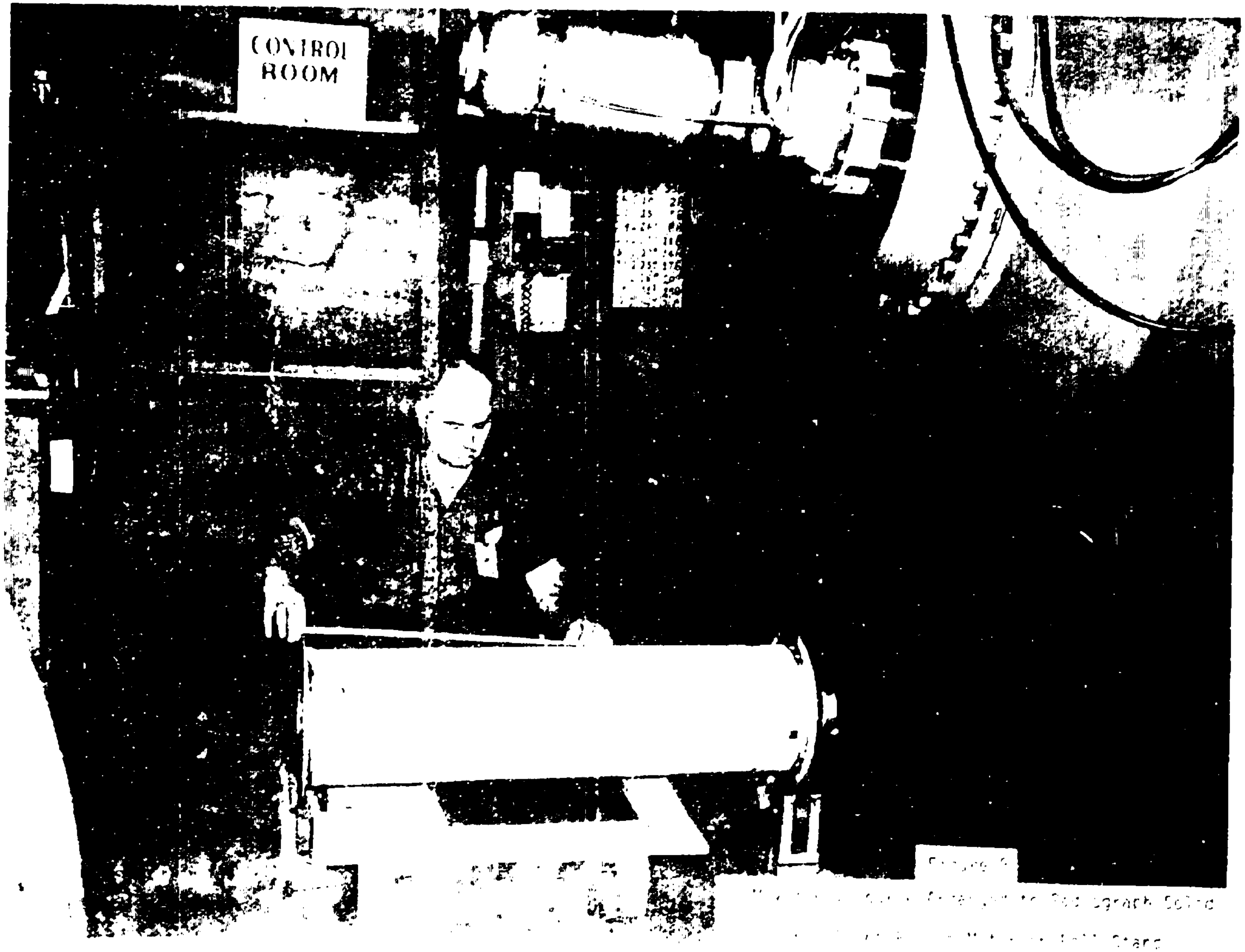


Figure [illegible]

[illegible] graph Solid

[illegible] Stand

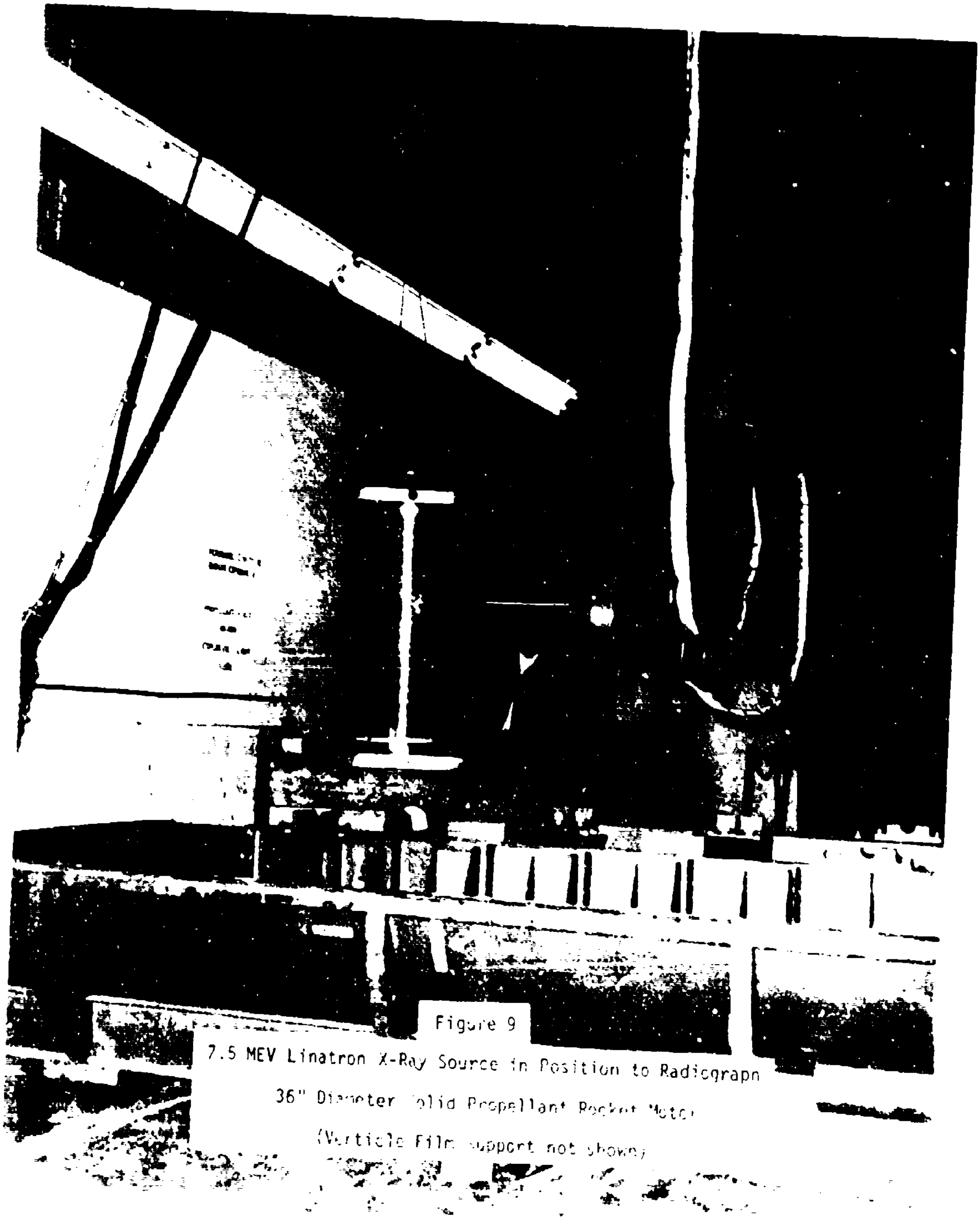
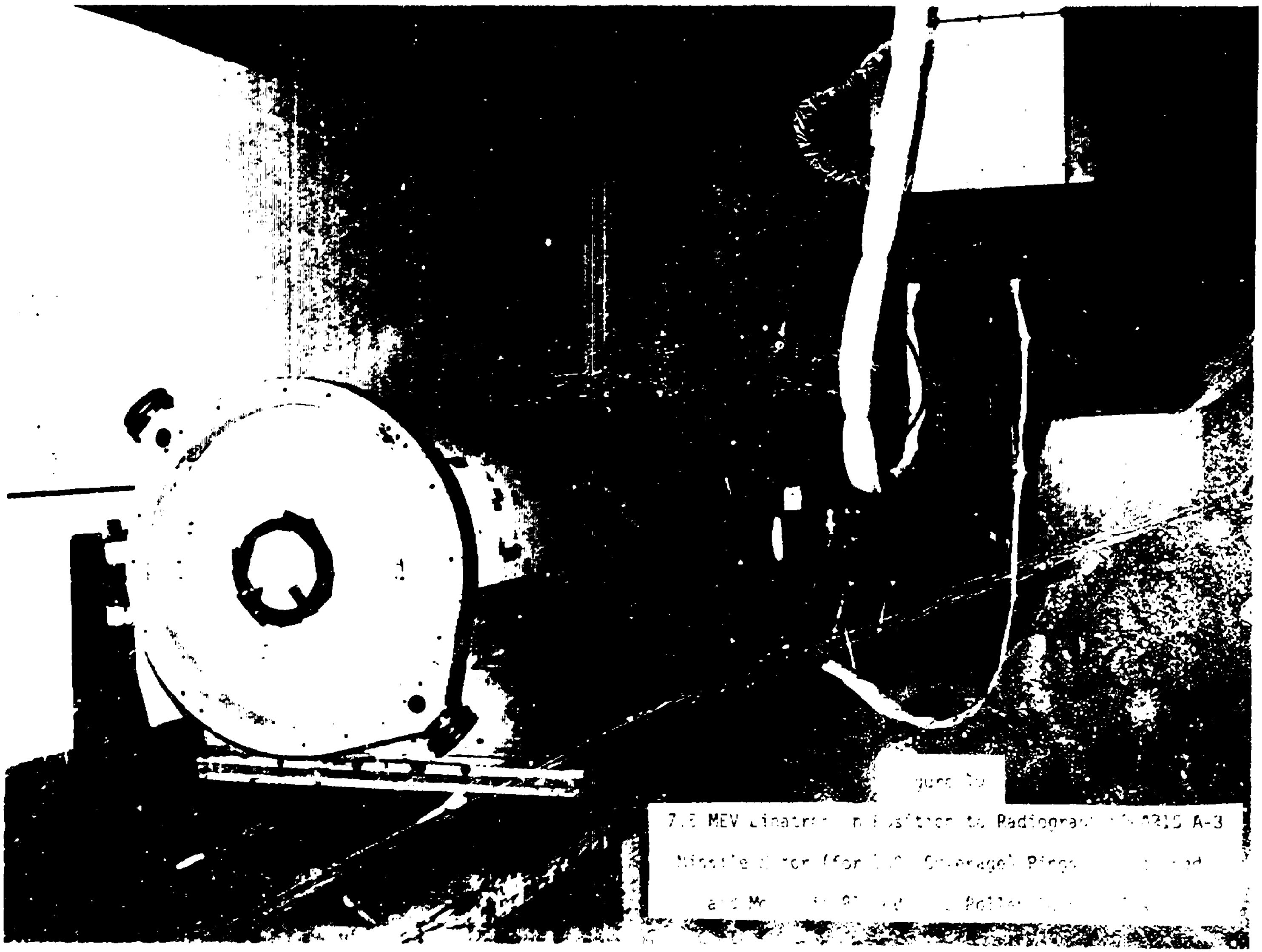


Figure 9

7.5 MEV Linatron X-Ray Source in Position to Radiograph

36" Diameter Solid Propellant Rocket Motor

(Verticle Film support not shown)



[illegible]gure 3b

7.5 MEV Linatron in Position to Radiograph [illegible] A-3 Missile [illegible] for [illegible] Coverage [illegible] [illegible] and M[illegible] [illegible] Roller [illegible]

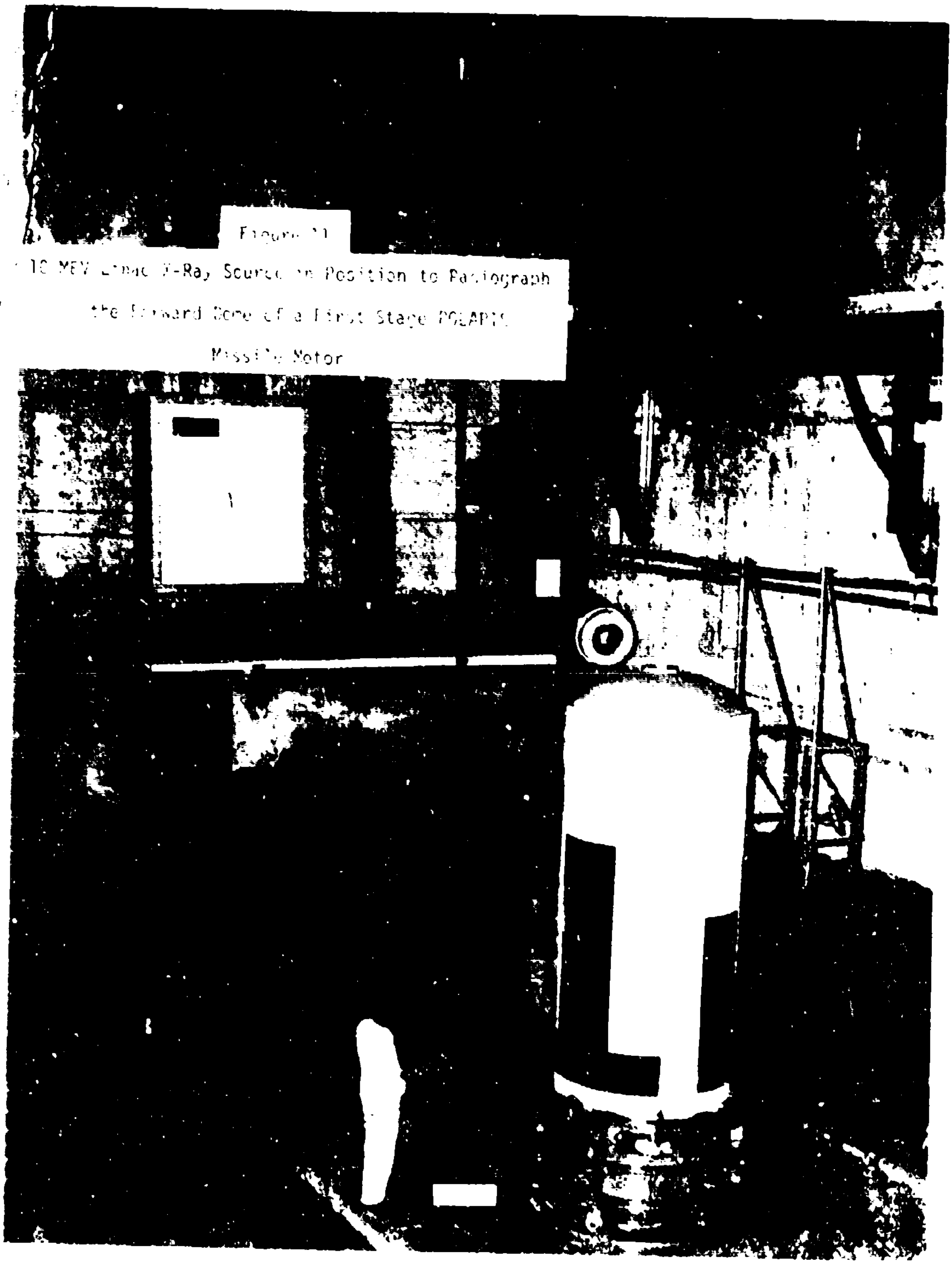


Figure 31

10 MEV Linac X-Ray Source in Position to Radiograph the Forward Dome of a First Stage POLARIS Missile Motor

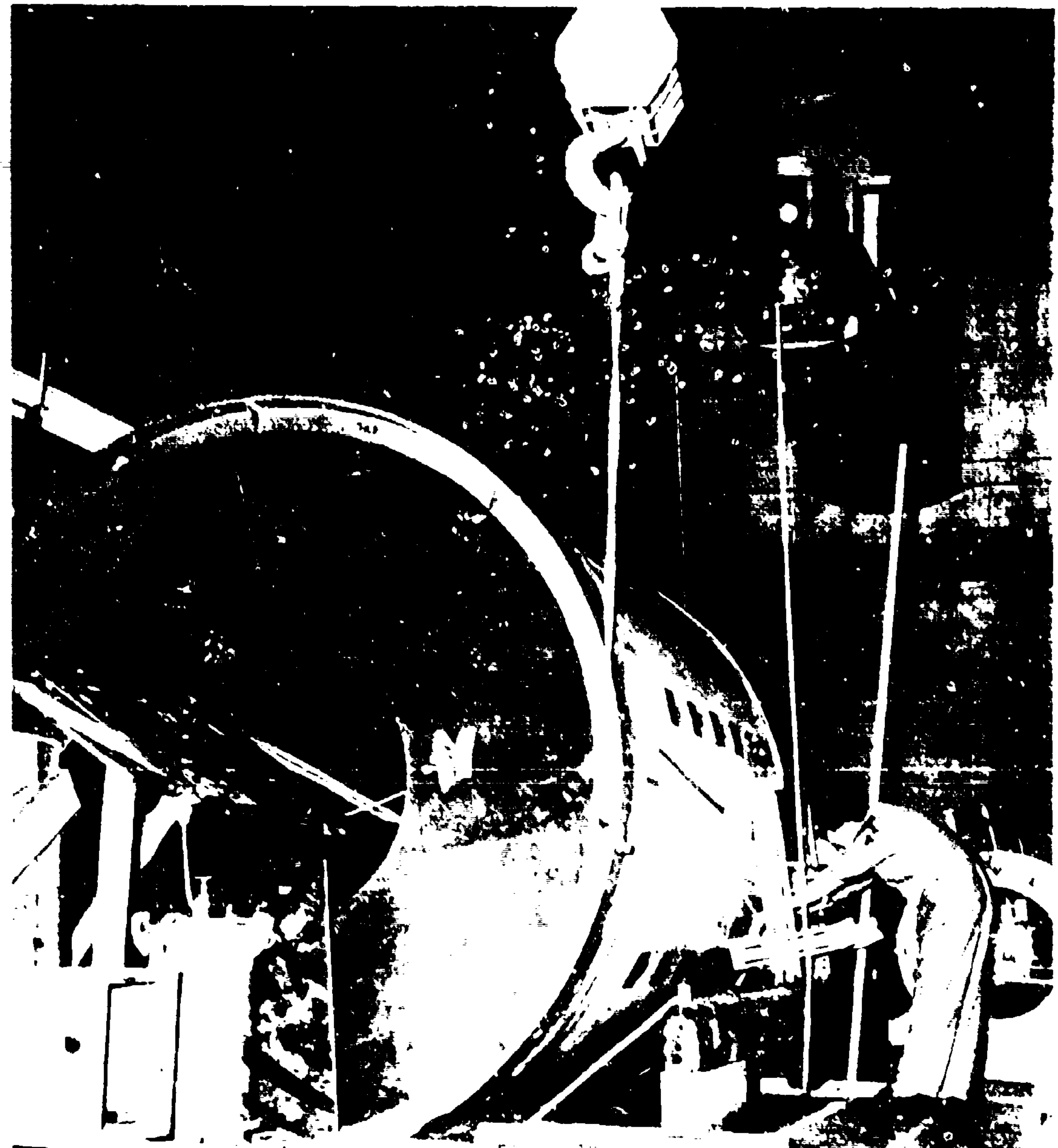


Figure 1[illegible]

10 MEV Linac in Position to Radiograph

[illegible] Solid Propellant Rocket Motor

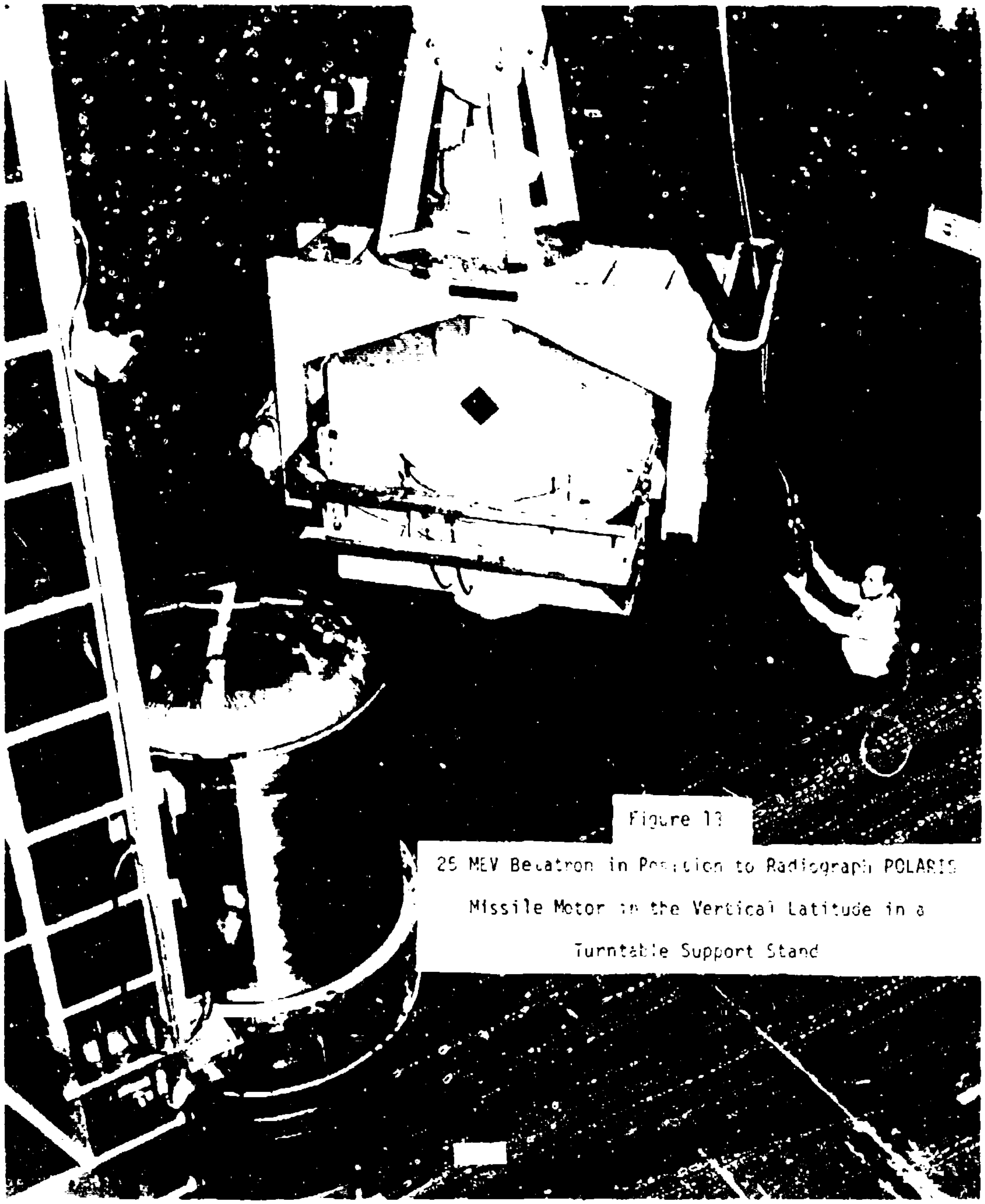


Figure 13

25 MEV Betatron in Position to Radiograph POLARIS Missile Motor in the Vertical Latitude in a Turntable Support Stand

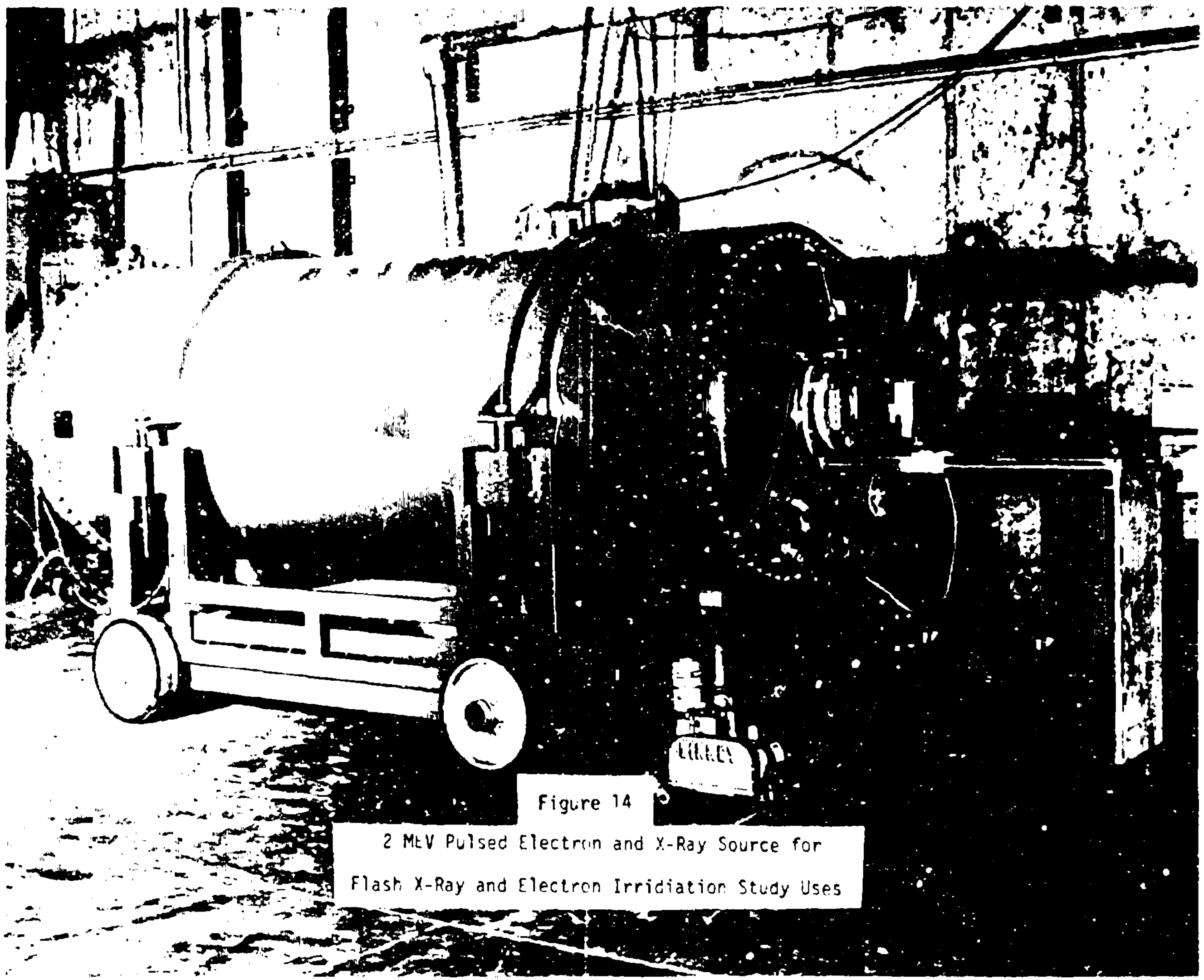


Figure 14

2 MeV Pulsed Electron and X-Ray Source for Flash X-Ray and Electron Irridiation Study Uses

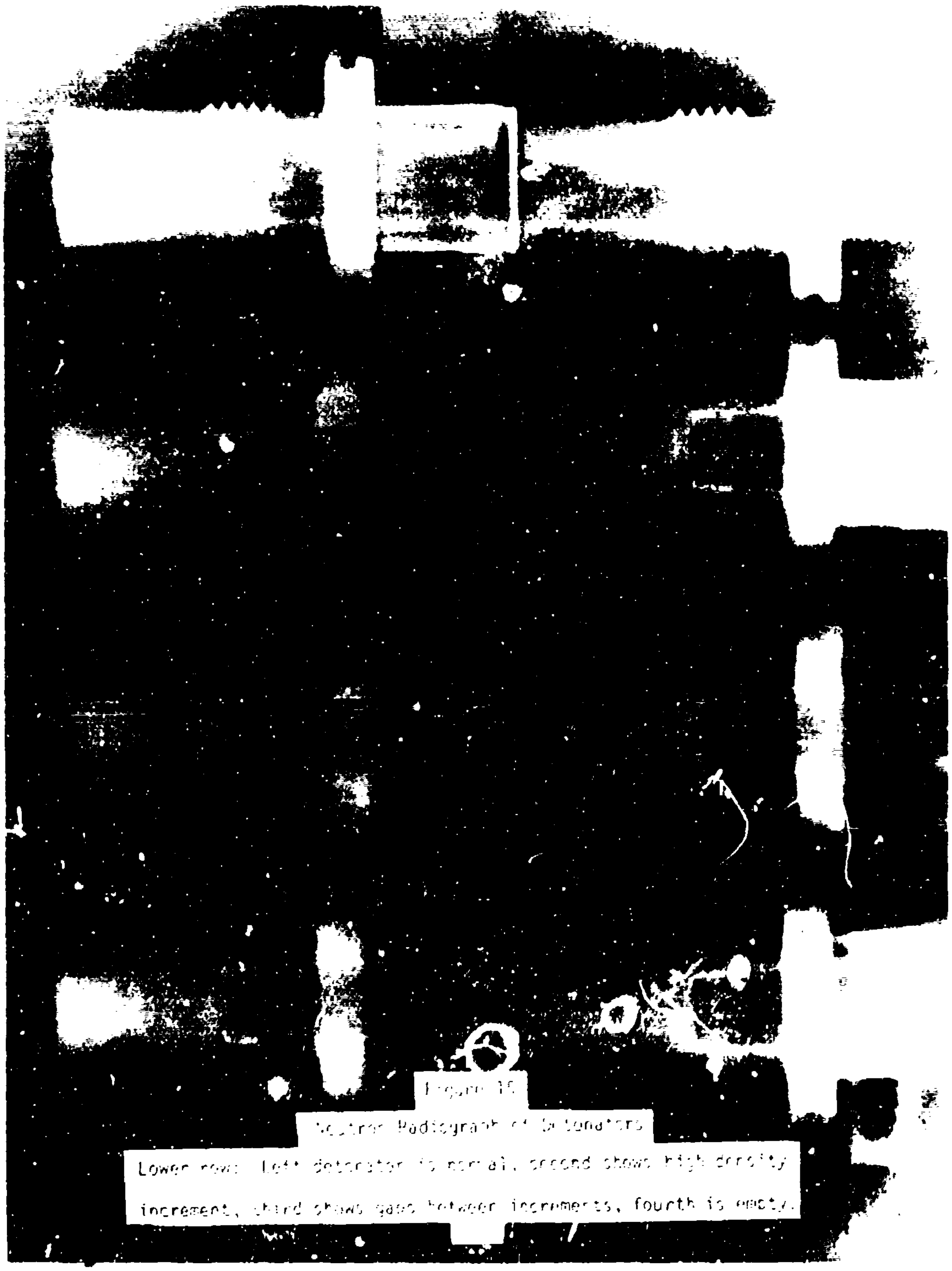


Figure 15

Neutron Radiograph of Detonators

Lower row: Left detonator is normal, second shows high density increment, third shows gaps between increments, fourth is empty.

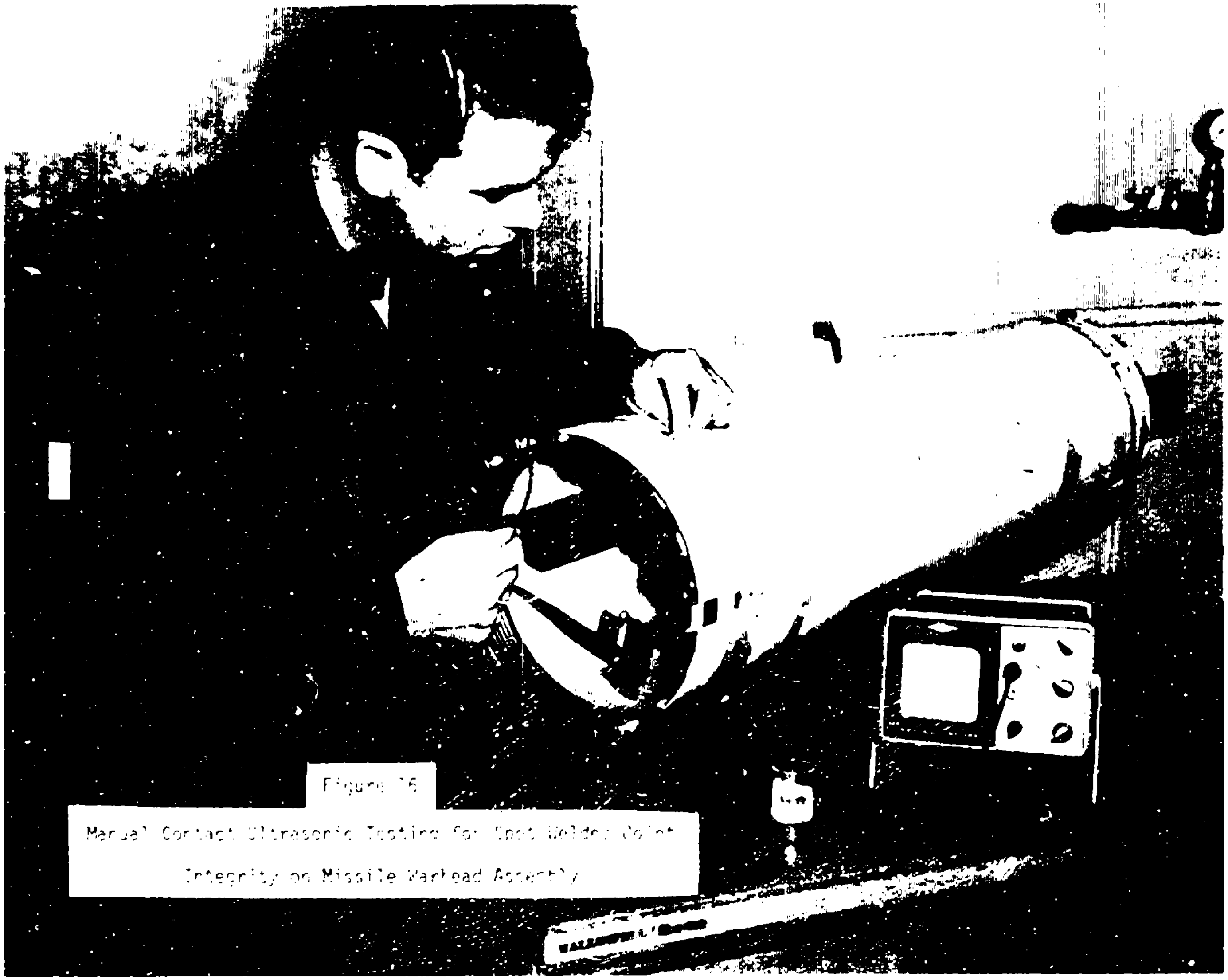
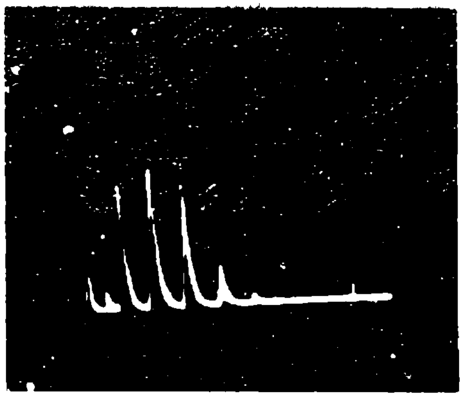


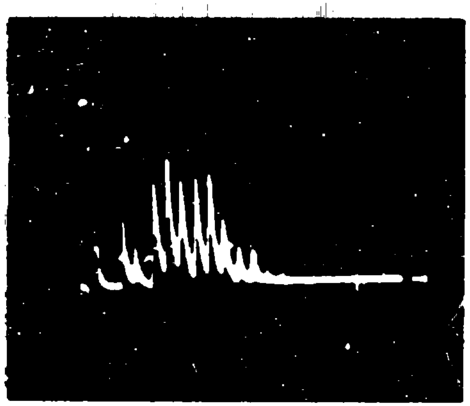
Figure 16

Manual Contact Ultrasonic Testing for Spot Welded Joint Integrity on Missile Warhead Assembly

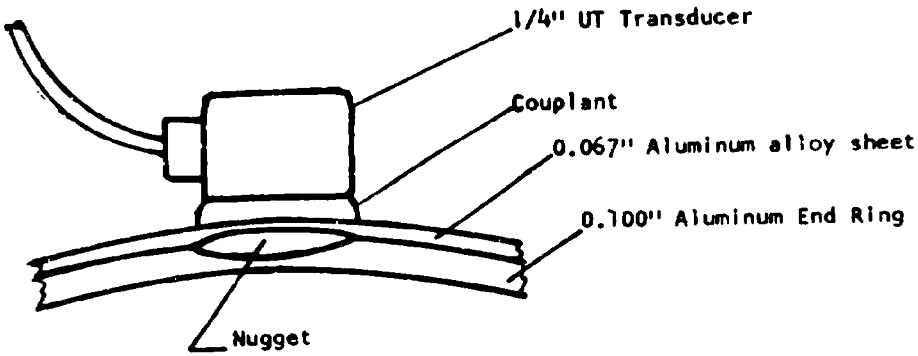
Full 3/16" spot weld



Approx. 1/16" spot weld



No spot weld



Equipment : Sperry Model UCD Reflectoscope

Frequency : 5 mc - L mode

Transducer: Automation Industries 1/4" diam. type SFZ-5 mc

Couplant : Glycerine, water, and wettner

Figure 17

Ultrasonic Test Indications in the Spot Weld Test

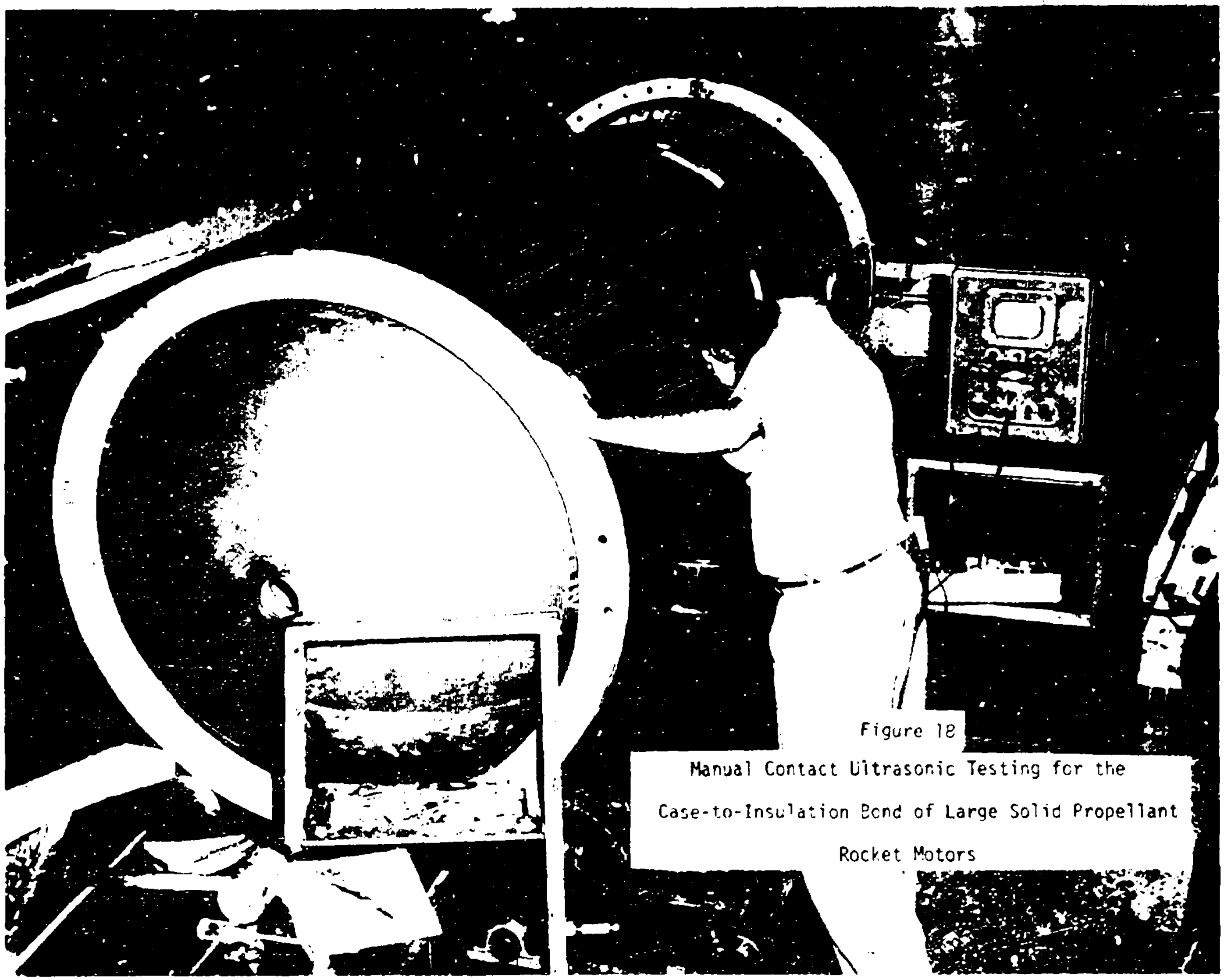


Figure 18

Manual Contact Ultrasonic Testing for the Case-to-Insulation Bond of Large Solid Propellant Rocket Motors

Figure 19

Operator applying the transducer and special wedge adapter to the base of a 5-inch projectile for the shear wave ultrasonic test of the base fuze

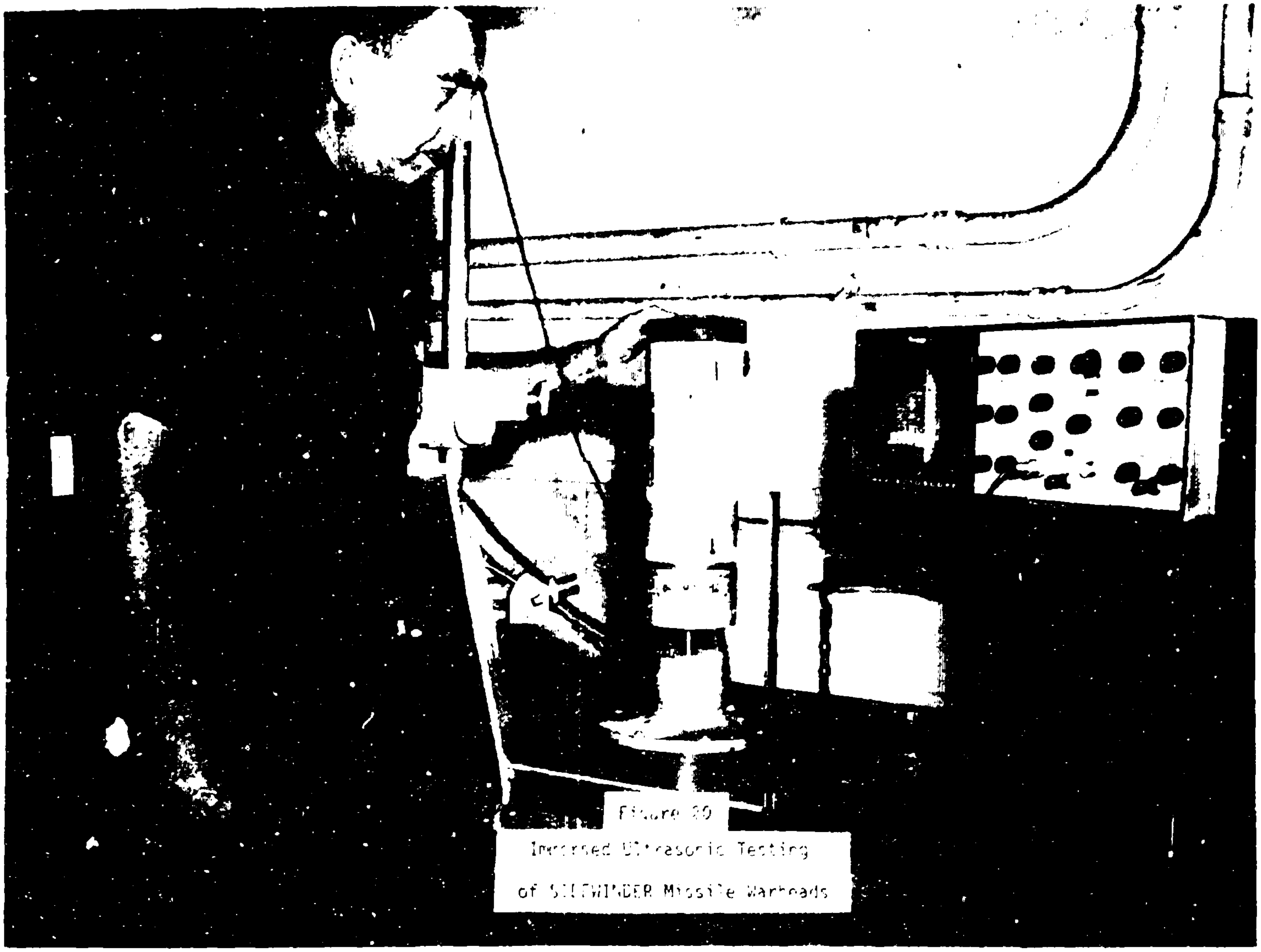


Figure 30

Immersed Ultrasonic Testing

of SIDEWINDER Missile Warheads

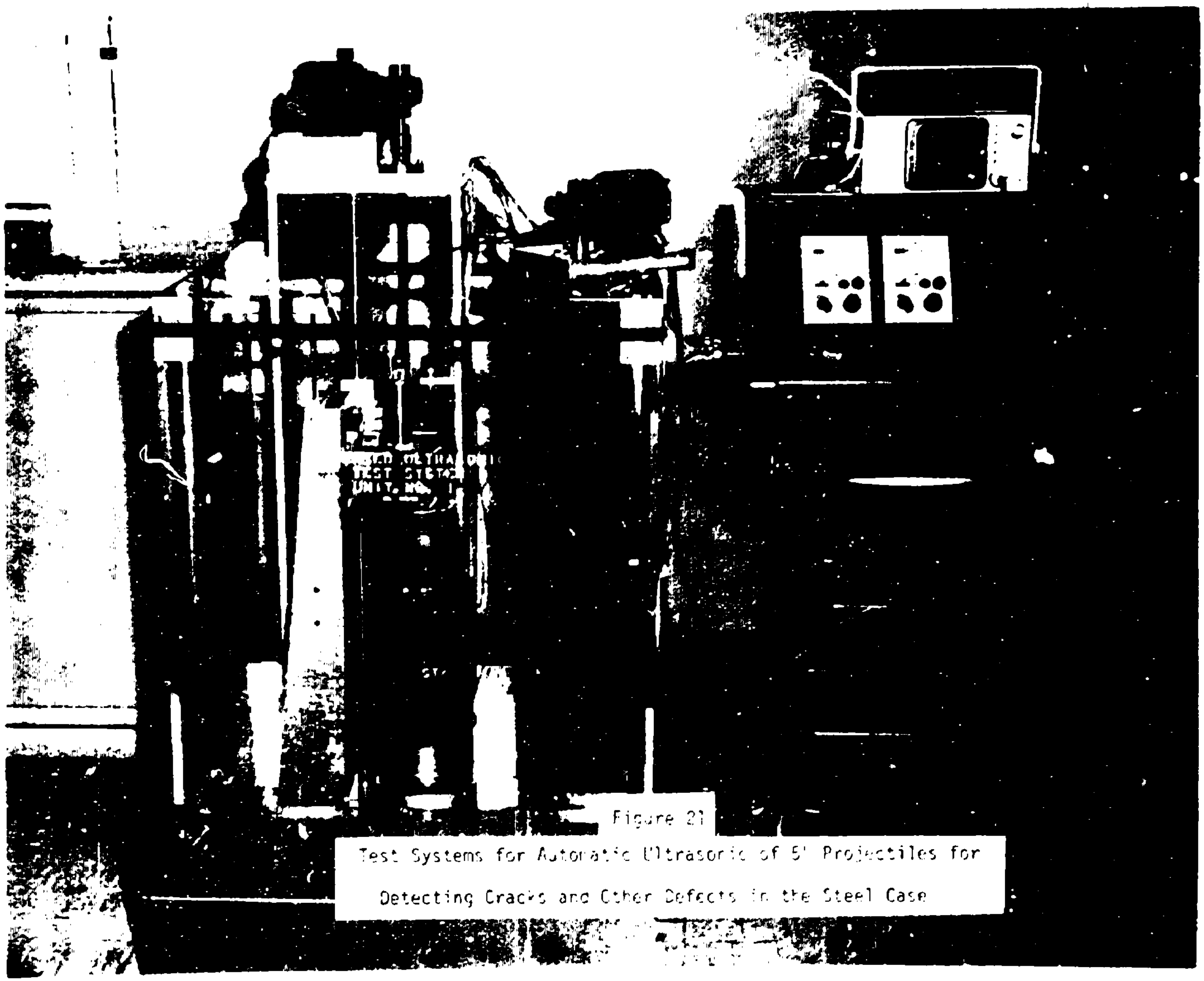


Figure 21

Test Systems for Automatic Ultrasonic of 5" Projectiles for Detecting Cracks and Other Defects in the Steel Case

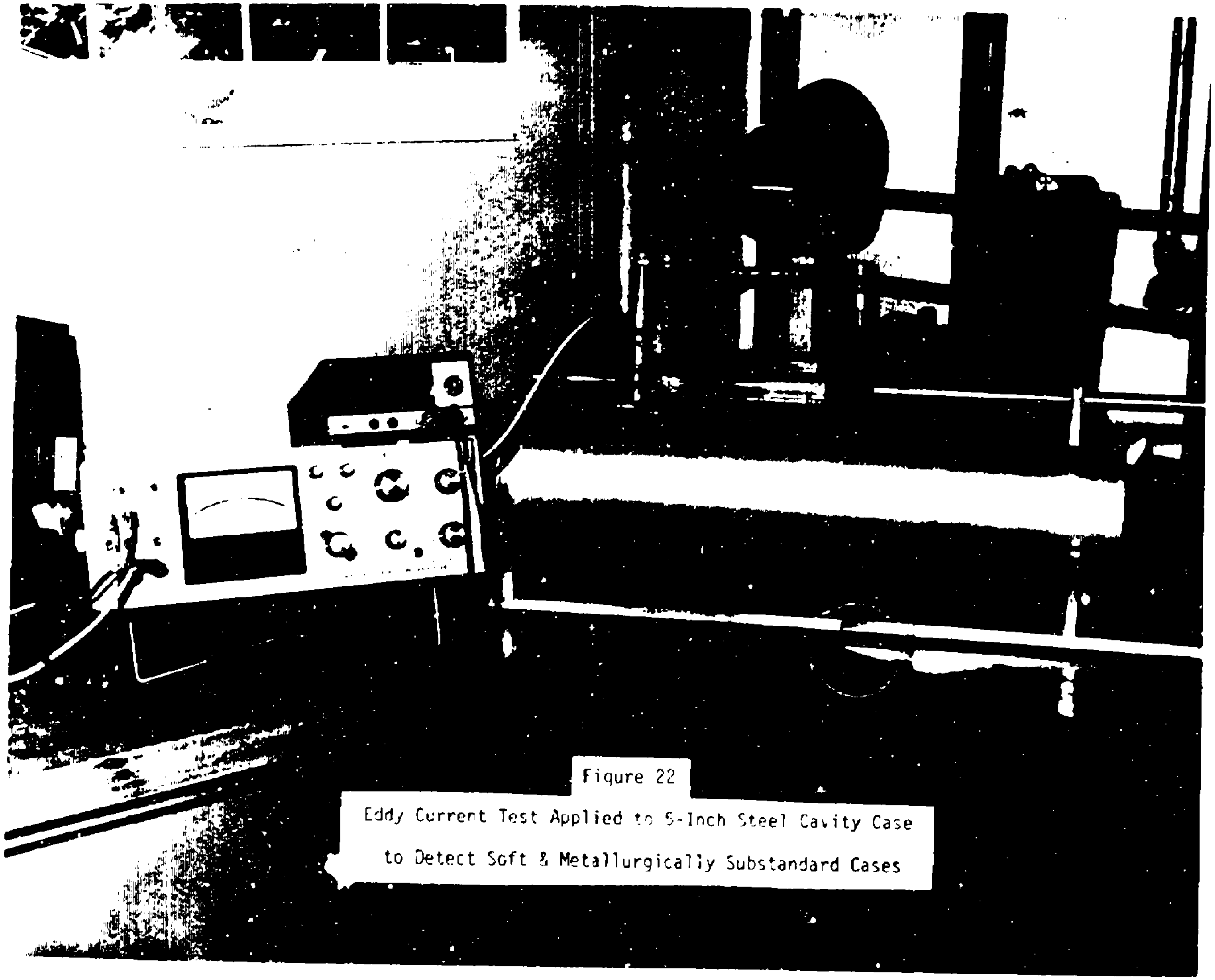


Figure 22

Eddy Current Test Applied to 5-Inch Steel Cavity Case to Detect Soft & Metallurgically Substandard Cases

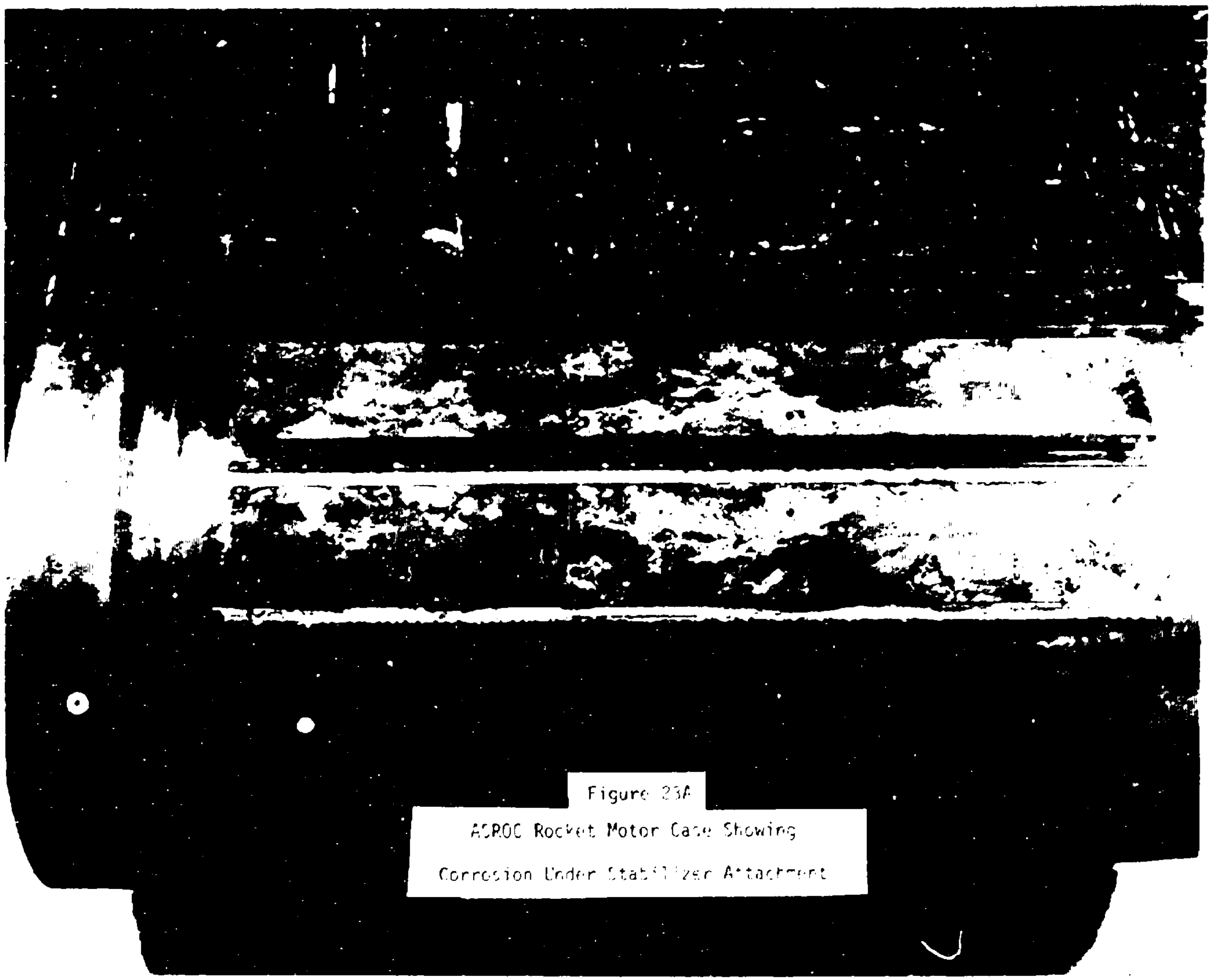


Figure 23A

ASROC Rocket Motor Case Showing

Corrosion Under Stabilizer Attachment

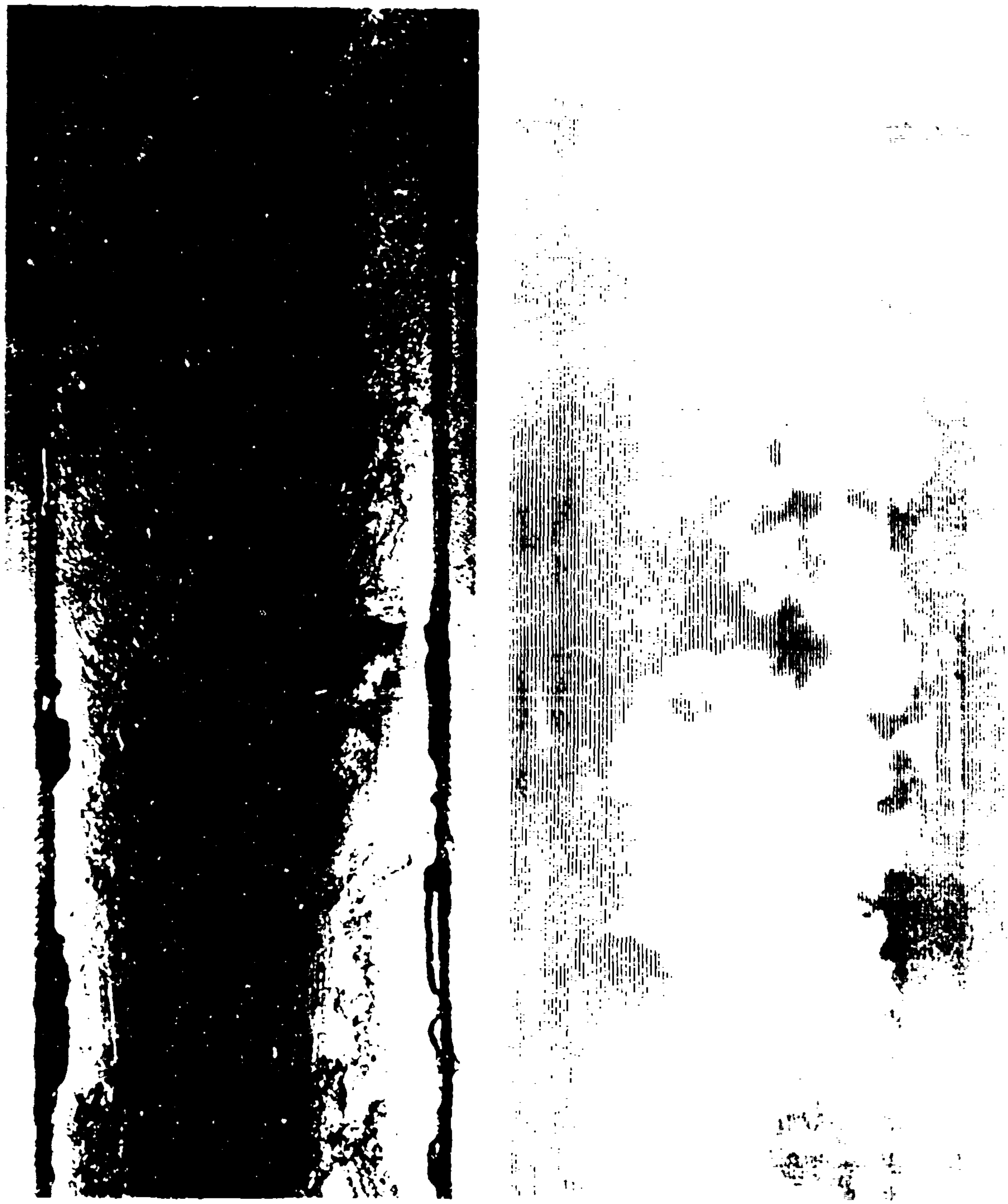


Figure 23B

Visual and Ultrasonic Patterns of ASROC

Motor Case Corrosion

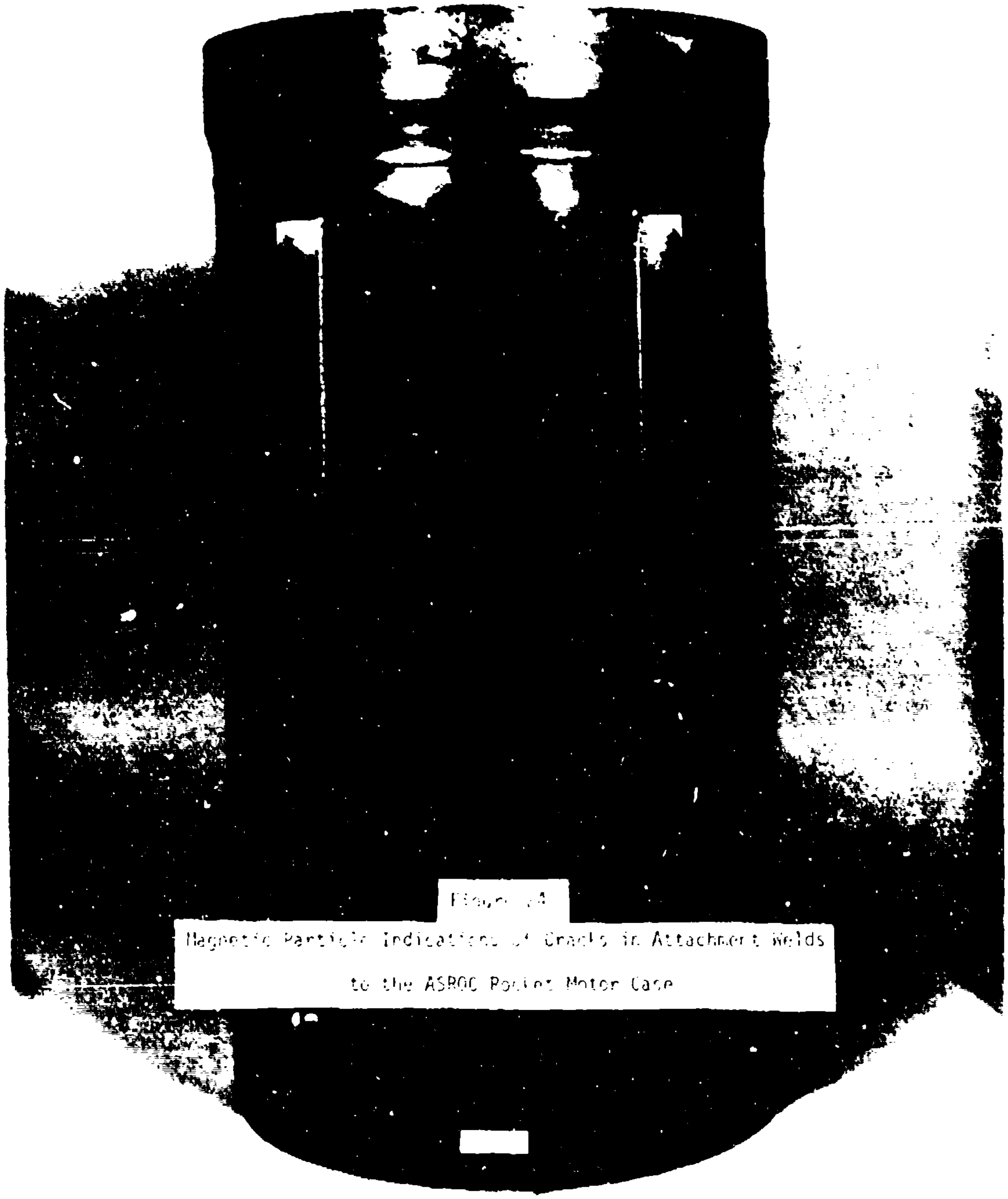


Figure [illegible]4

Magnetic Particle Indications of Cracks in Attachment Welds to the ASROC Rocket Motor Case

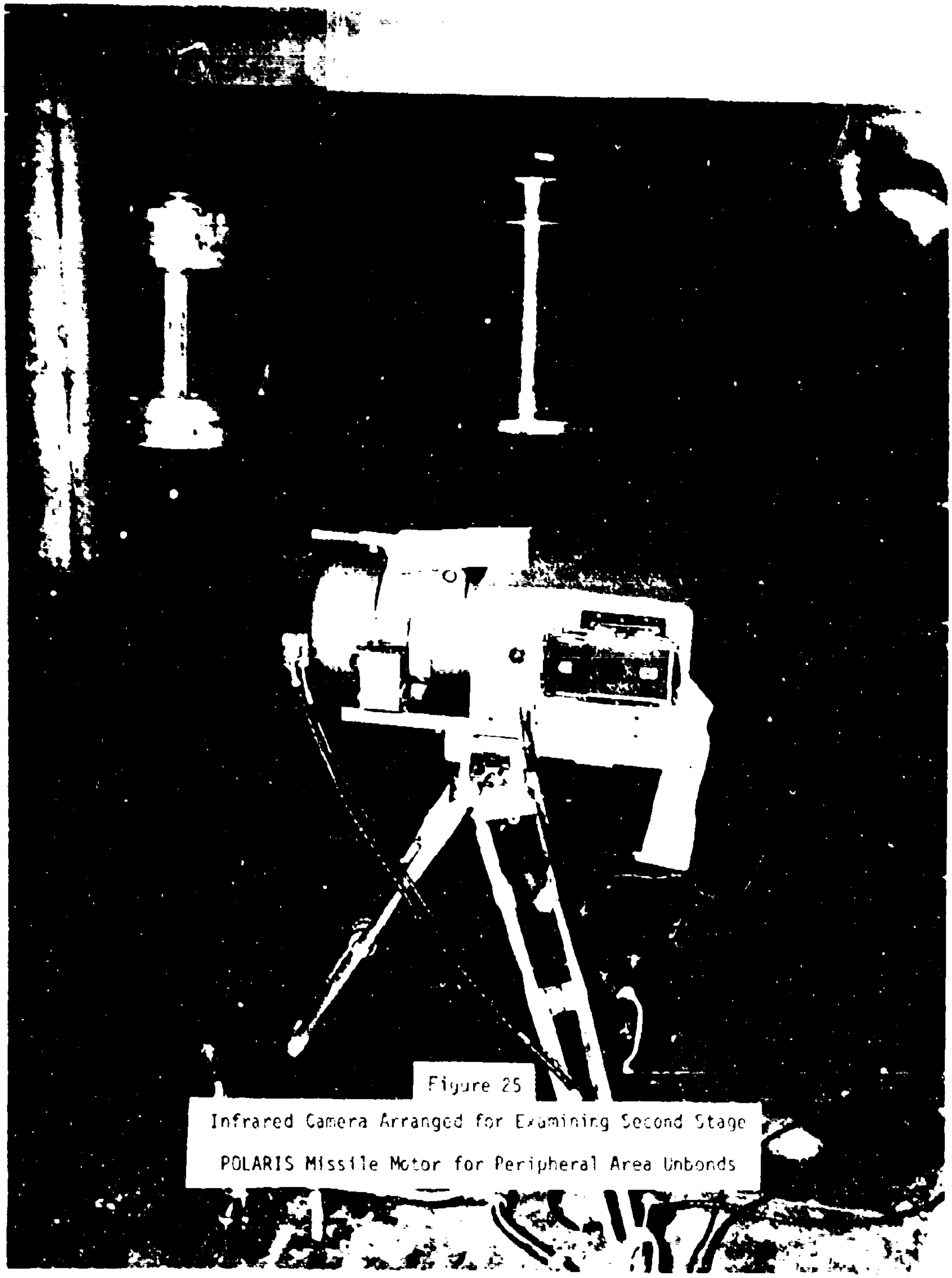
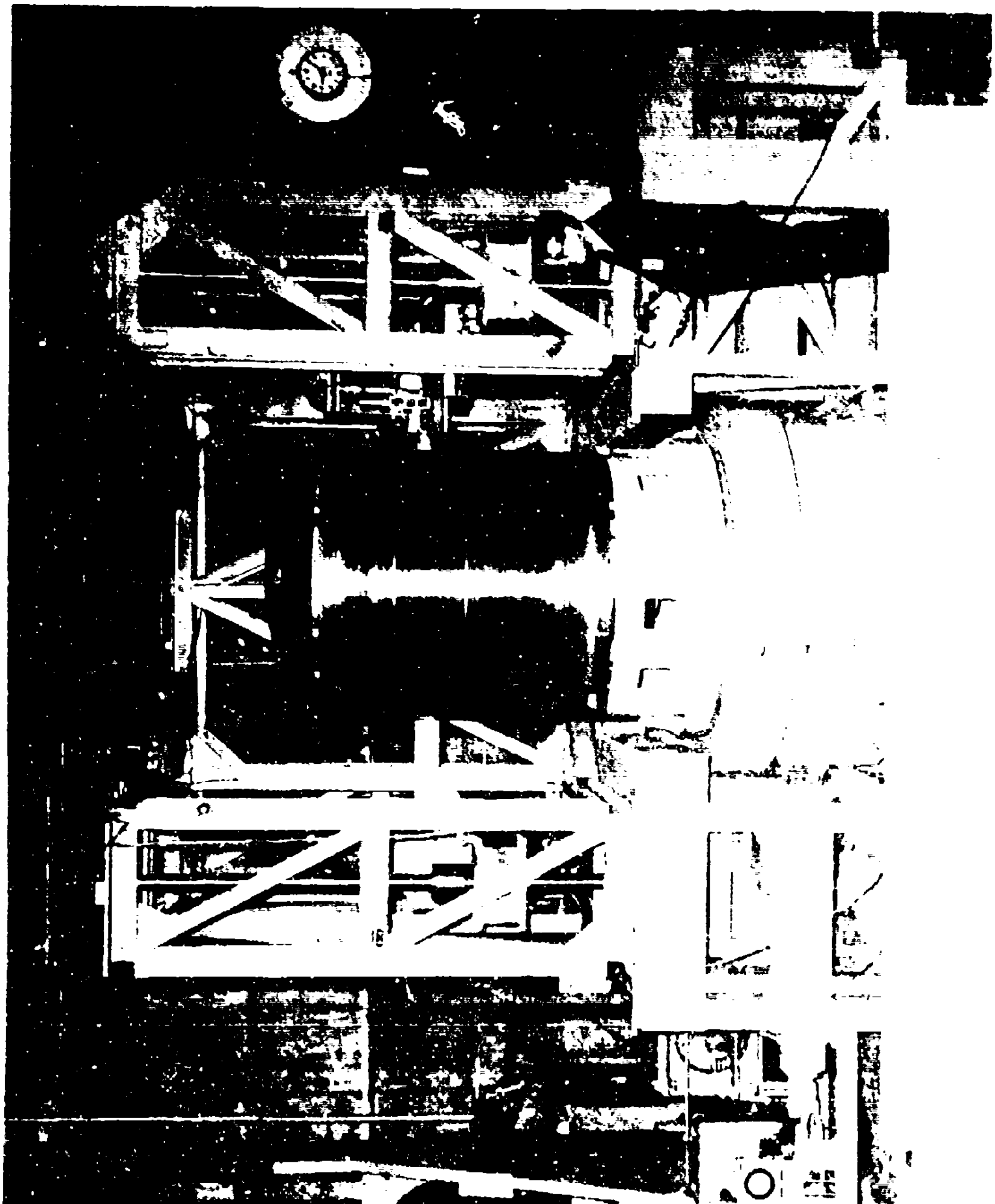


Figure 25

Infrared Camera Arranged for Examining Second Stage POLARIS Missile Motor for Peripheral Area Unbonds



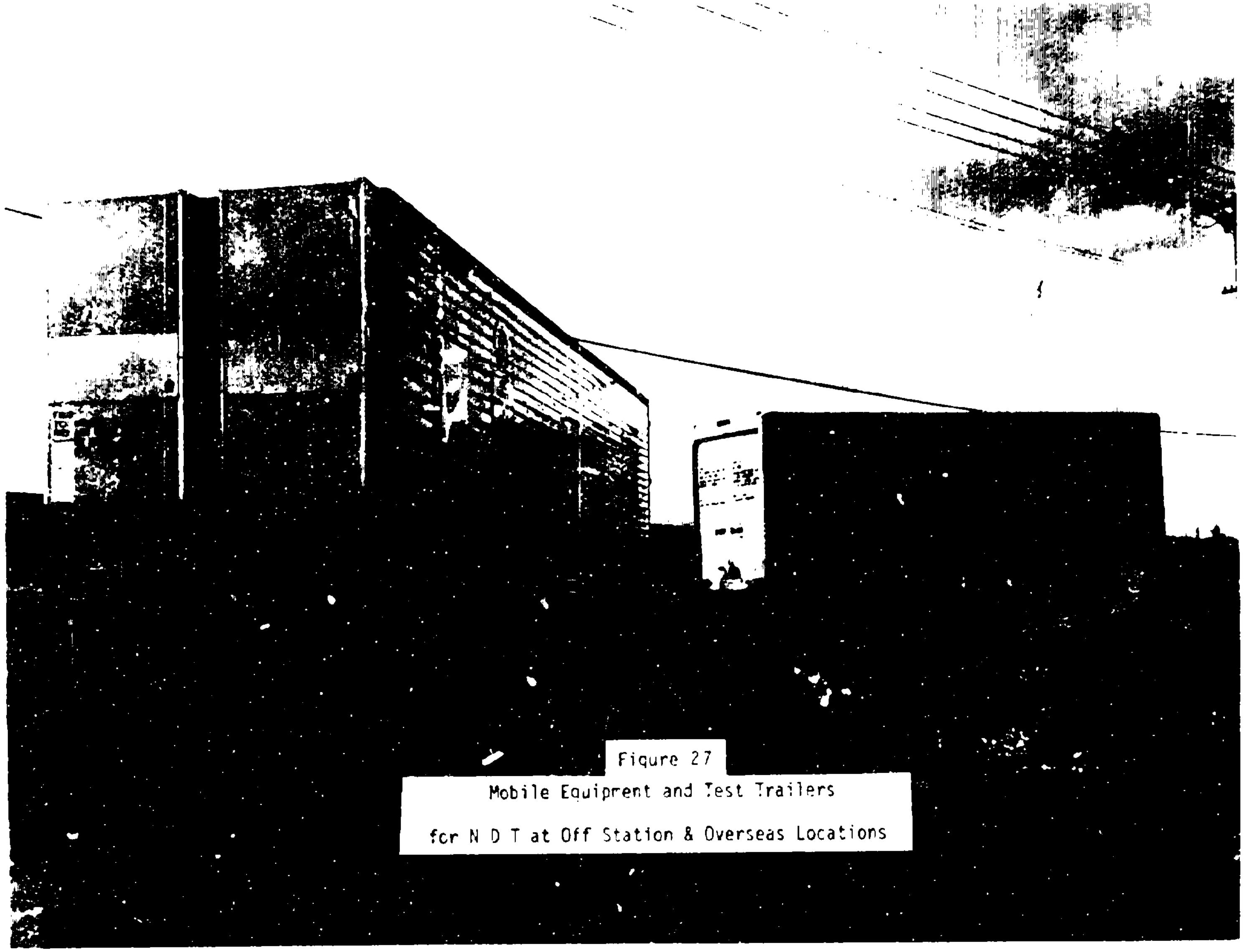


Figure 27

Mobile Equipment and Test Trailers

for N D T at Off Station & Overseas Locations

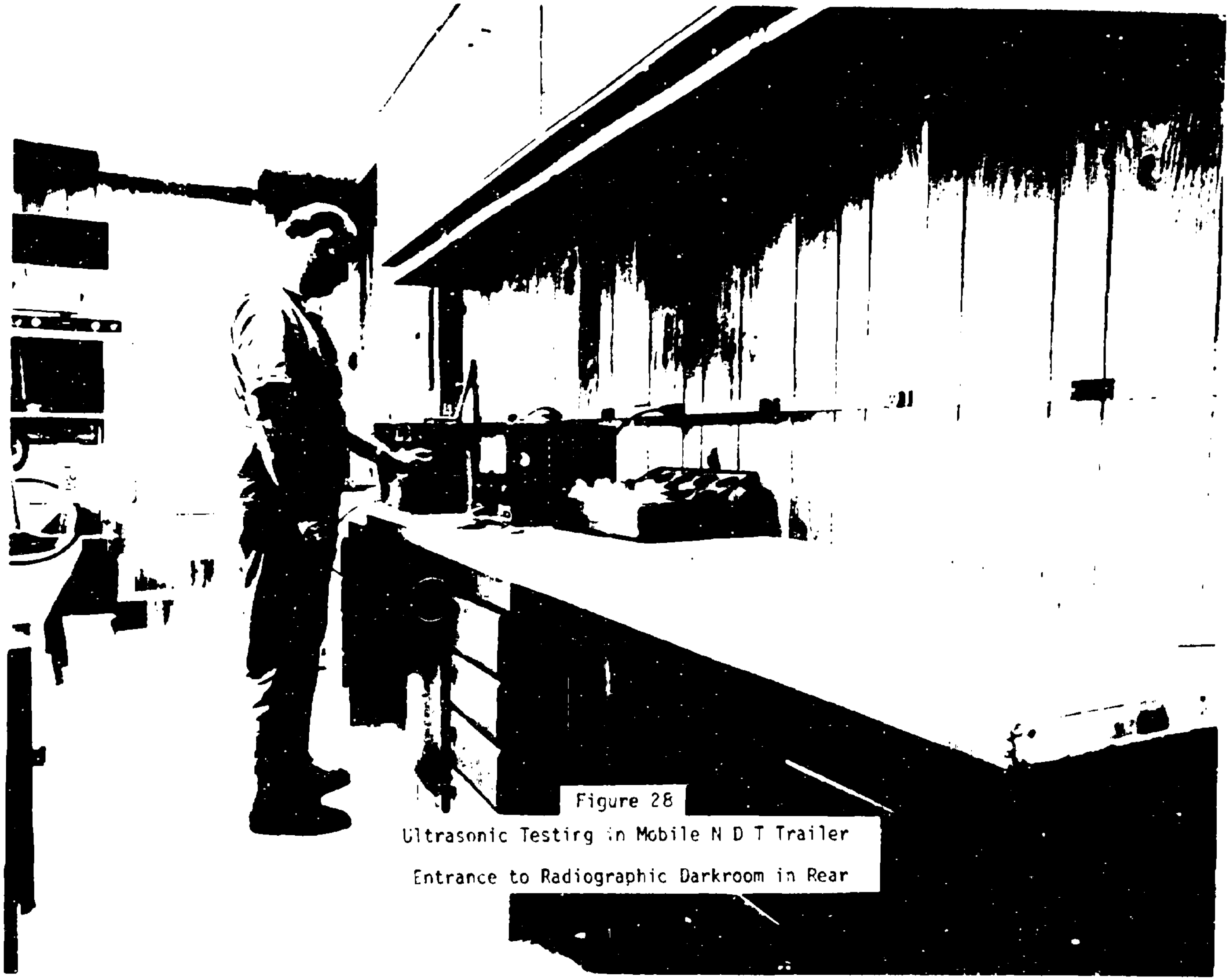


Figure 28

Ultrasonic Testing in Mobile N D T Trailer

Entrance to Radiographic Darkroom in Rear

EXPLOSIVE DISPOSAL BY CONFINED SPACE SHOTS

J. E. Sinclair and K. J. Graham

Naval Postgraduate School
Monterey, California 93940

ABSTRACT

In a laboratory-scale confined chamber, the percentage concentrations of the major gaseous products evolved from the disposal of military secondary high explosives as well as for homogeneous solid propellants were determined. The gaseous product analysis was determined by gas chromatrography and was compared to the theoretically predicted gaseous products for ideal explosive detonation and deflagration.

It was shown that the concentration of the evolved gases stabilized as the amount of explosive increased and the steady-state chamber pressures observed were relatively low.

Scale-up of the laboratory model to an actual size disposal chamber, such as a solution-mined salt dome, indicated that large quantities of explosives could be disposed of with predictable gaseous product concentrations and low steady-state chamber pressures.

Examination of the locations of such salt domes, the costs involved in the preparation of the facility, the operational safety, and the minimization of environmental impact indicates that confined space disposal of waste explosives would be an attractive alternative to the current explosive disposal problem.

INTRODUCTION. Recent public and governmental concern over polluting materials and their discharge into the environment has caused the military to take a closer look at its methods of explosives disposal. Current methods of disposal include open burning, incineration, open detonation, biochemical degradation, chemical recovery and deep ocean dumping. Each of these methods is in some way unsatisfactory to the environmentalist on the basis of trade-offs that must be made between safety, cost, and environmental impact. For example, the open burning of 3.8 tons of trinitrotoluene produces 625 pounds of soot alone, in addition to the toxic gases

such as carbon monoxide and nitrogen oxides, and the increased thermal loading of the atmosphere. Another example concerns the chemical recovery of trinitrotoluene by steam washout, which has had the effect of producing high amounts of nitrates and nitrites in some stream and river waters, producing eutrophication and, in general, upsetting the ecological balance of the biosphere. A similar situation exists in deep ocean dumping in which marine life may be destroyed by the toxic chemicals in the explosive.

Work has begun around the country in both military and civilian research laboratories to find acceptable ways to dispose of waste materials such as explosives and toxic chemicals. We have chosen to examine the disposal of explosives by detonation and/or deflagration in a closed space.

The idea of disposing of explosives in a confined space originally came from the work of Young [1] at the Naval Postgraduate School, and was later expanded upon by Visted [2]. This concept envisioned large batch quantities of explosives being destroyed in an underground confined space, such as the salt chambers that have been used by the Atomic Energy Commission. The resultant polluting products could then either be vented to processing equipment, to the atmosphere during meteorologically acceptable conditions, or kept contained for long periods of time.

In order to understand the processes that would occur if this idea were adopted, it was necessary to (1) identify the products of the explosion, (2) determine the concentrations of the products of the explosion, and (3) to measure the static pressure in the chamber after the explosion.

EXPERIMENTAL. We have constructed a stainless steel cylinder with a capacity of 19.57 ℓ, with an airlock provision for loading consecutive samples of explosives into the chamber without changing the product concentration

of the pressure by more than .25% per loading. Loading was accomplished by placing a blasting cap and a paper cartridge containing the explosive of interest into the cylinder through the airlock and firing it remotely through the electrical fixture passing through the center of the airlock shaft. Figure 1 shows the sample chamber. Figure 2 shows the electrical hook-up through the airlock.

Test samples were the major military secondary high explosives listed in Table I and the homogeneous solid propellants listed in Table II. In a typical run, the sample was loaded into the paper cartridge and attached to the blasting cap. This unit was then connected to the wires of the firing circuit and lowered into the cylinder through the airlock. The shot was fired remotely and time was allowed for the sufficient mixing of product gases. Three samples were then withdrawn through the sample valve into evacuated containers for analysis by gas chromatography. A Fisher Gas Partitioner modified to include a third column freezing trap was used for the gas analysis. Gases studied were oxygen, carbon monoxide, carbon dioxide and nitrogen-nitrogen oxides. Hydrogen and methane were also attempted but were not observed in the sensitivity range of the chromatograph. Following the withdrawal of the samples, another charge was placed into the chamber through the airlock and the whole process repeated until many grams of explosive had been used. After the final shot of a series and withdrawal of the three samples, the static pressure was measured using a pressure gauge attached to the sample valve.

No attempt was made to control the wall temperature of the cylinder or to decouple the shock from the cylinder walls. Also, pure compounds were used for the explosive test samples rather than cased ammunition.

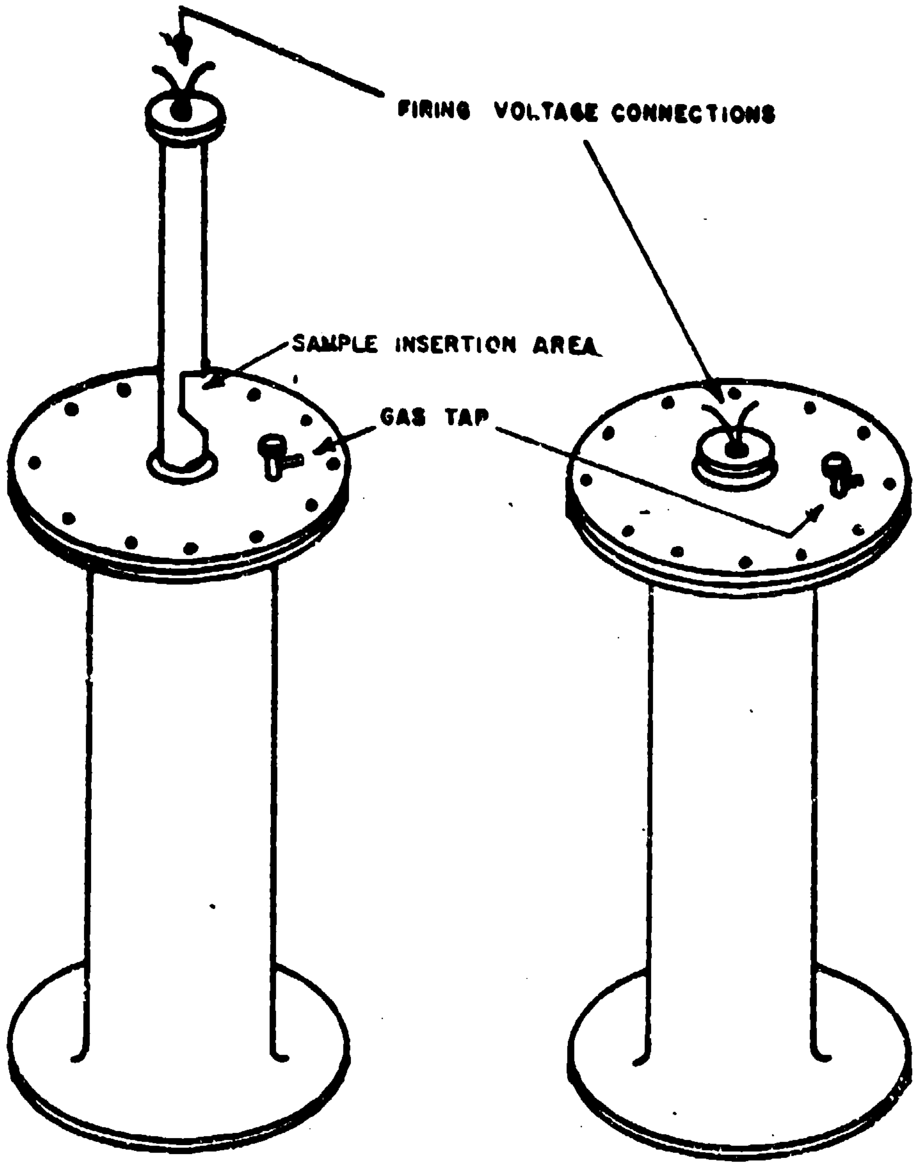


FIGURE 1: LOADING AND FIRING POSITIONS

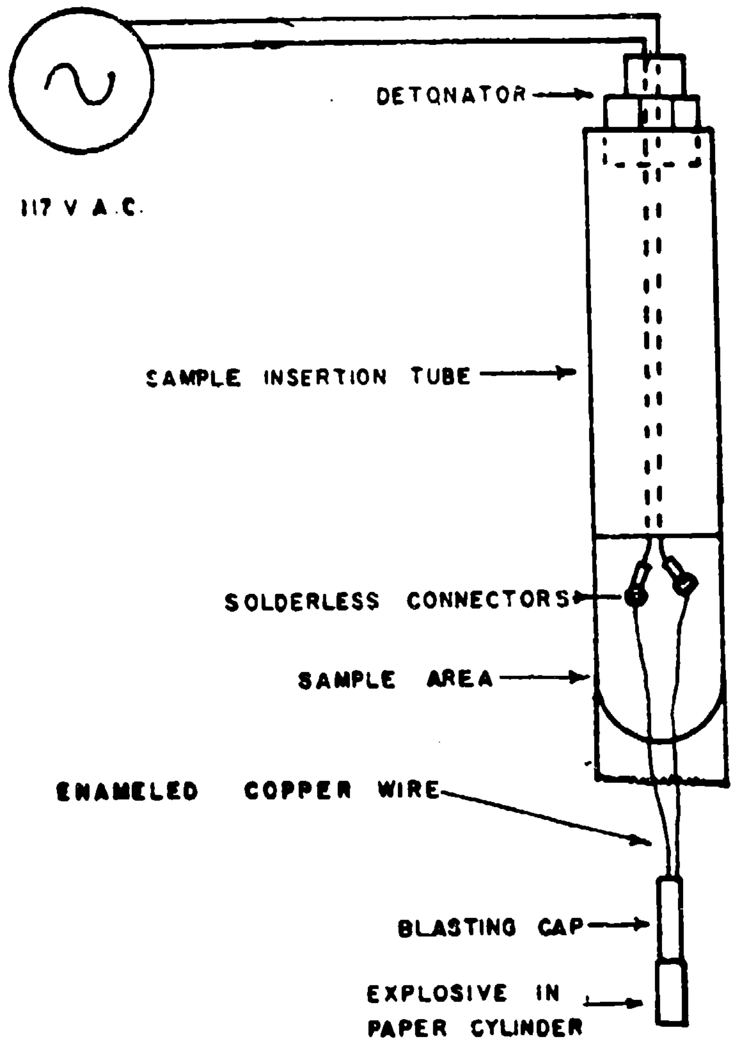


FIGURE 2: DETAIL OF FIRING ASSEMBLY

TABLE I

TEST SECONDARY HIGH EXPLOSIVE CHARACTERISTICS

TRINITROTOLUENE (TNT) -- $C_7H_5N_3O_6$

Molecular Weight	227.1
Oxygen Balance	
CO_2	-74
CO	-25
Relative Power (%)	100

CYCLOTETRAMETHYLENETETRANITRATE (HMX) -- $C_4H_8N_8O_8$

Molecular Weight	296
Oxygen Balance	
CO_2	-21.6
CO	0.0
Relative Power (%)	150

CYCLOTRIMETHYLENETRINITRAMINE (RDX) -- $C_3H_6N_6O_6$

Molecular Weight	222
Oxygen Balance	
CO_2	-22
CO	0.0
Relative Power (%)	150

PENTAERYTHRITOLTETRANITRATE (PETN) -- $C_5H_8N_4O$

Molecular Weight	316
Oxygen Balance	
CO_2	-10
CO	15
Relative Power (%)	145

COMPOSITION C-4 (91% RDX, 9% Plasticizer)

Molecular Weight	100
Oxygen Balance	
CO_2	-48
CO	-23
Relative Power (%)	130

TABLE II

HOMOGENEOUS SOLID PROPELLANT TEST SAMPLES

PROPELLANT 5066
PROPELLANT 2400
PROPELLANT 4198
PROPELLANT 4227

RESULTS. The results are examined in three groups, (1) the explosive cartridge itself, (2) the military secondary high explosives, and (3) the homogeneous solid propellants.

The explosive cartridge was a standard aluminum shell electric blasting cap containing approximately .315 grams of Pentaerythritoltetranitrate (PETN) as the main initiator and approximately 0.05 grams of heat sensitive lead styphnate as a primer. The paper cartridge weighed 0.55 grams. The blasting cap and paper shell combination weighed approximately 3.3 grams. An eight shot sequence was fired for a total of 30.1 grams of explosive cartridge. Changes in the gas composition are seen in Table III and Figures 3 - 6. The major gaseous products stabilized in percentage concentration in the area of 18-22 grams of explosive cartridge detonated. A significant point is the almost total absence of any carbon monoxide. The growth of the nitrogen and oxides of nitrogen percentage concentration was expected because of the nitrocellulose, PETN, and lead azide ingredients of the explosive cartridge.

The secondary high explosives tested which covered the spectrum from oxygen rich to oxygen poor, exhibited the same general type percentage concentration of gases evolved. From Figure 7, one can see that the oxygen percentage concentration exhibited a negative evolution as the oxygen was consumed, but stabilized at a constant level in the range of 10-12 grams of explosive detonated. The band of stabilization for the five test explosives varied from 3 to 6 percent oxygen concentration. In Figure 8, carbon dioxide concentration exhibited a positive evolution that stabilized at 8-10 grams of explosive detonated. The band of stabilization varied from 9-15 percent concentration. Figure 9 shows the positive evolution of

FIGURE 3: EXPLOSIVE CARTRIDGE PERCENT OXYGEN EVOLUTION

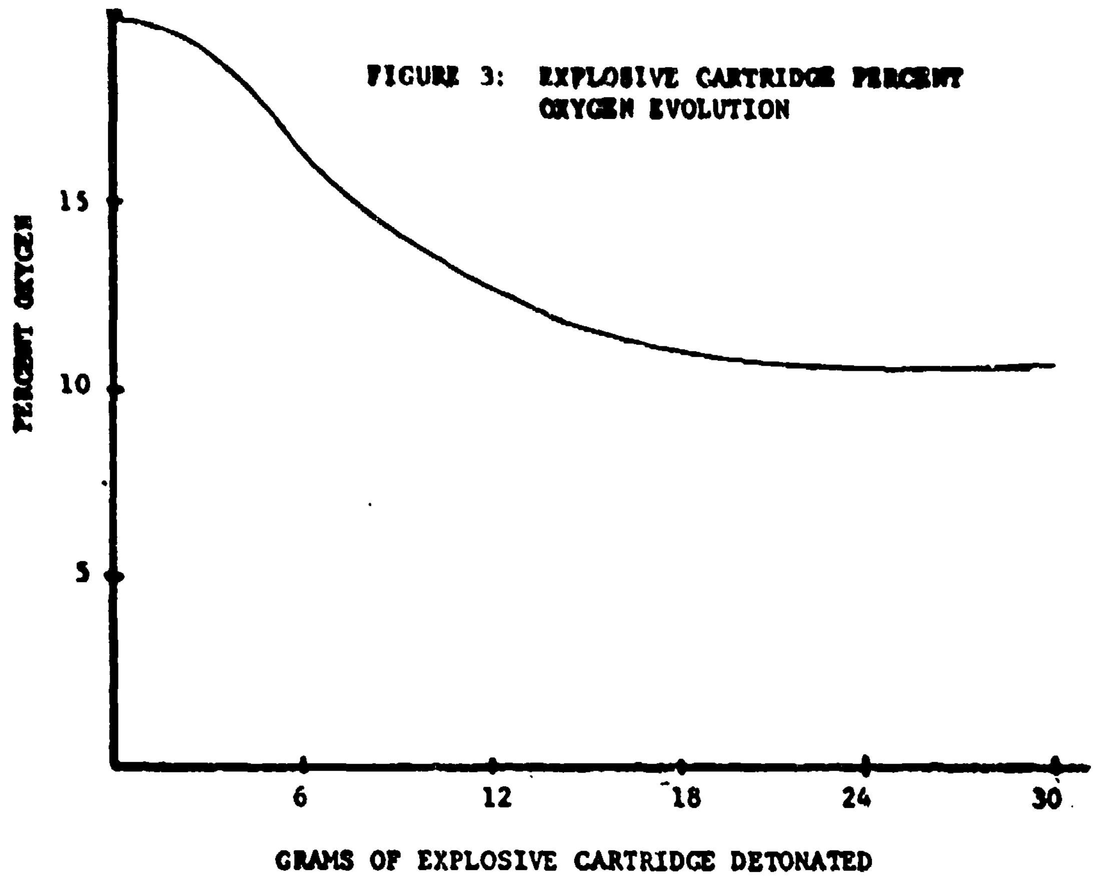
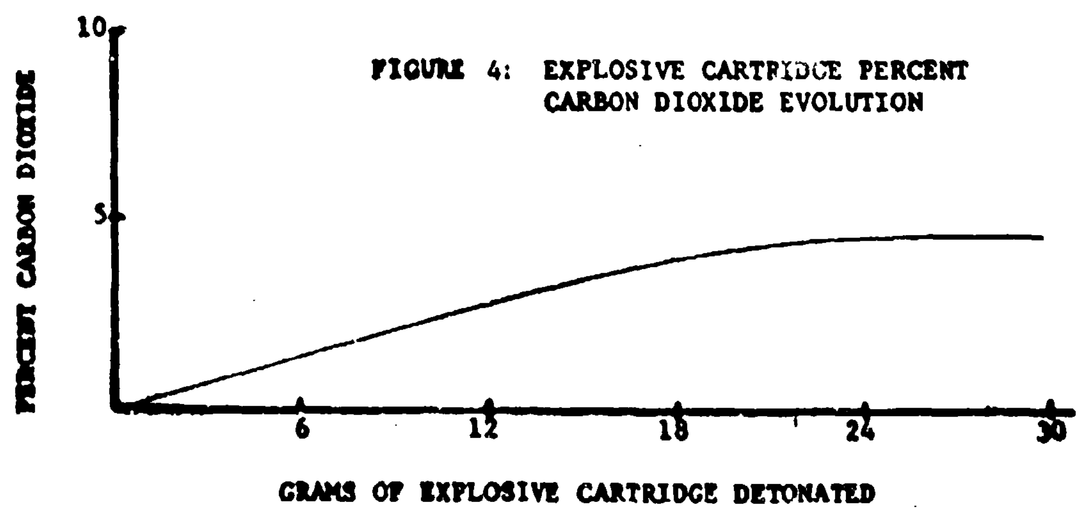


FIGURE 4: EXPLOSIVE CARTRIDGE PERCENT CARBON DIOXIDE EVOLUTION



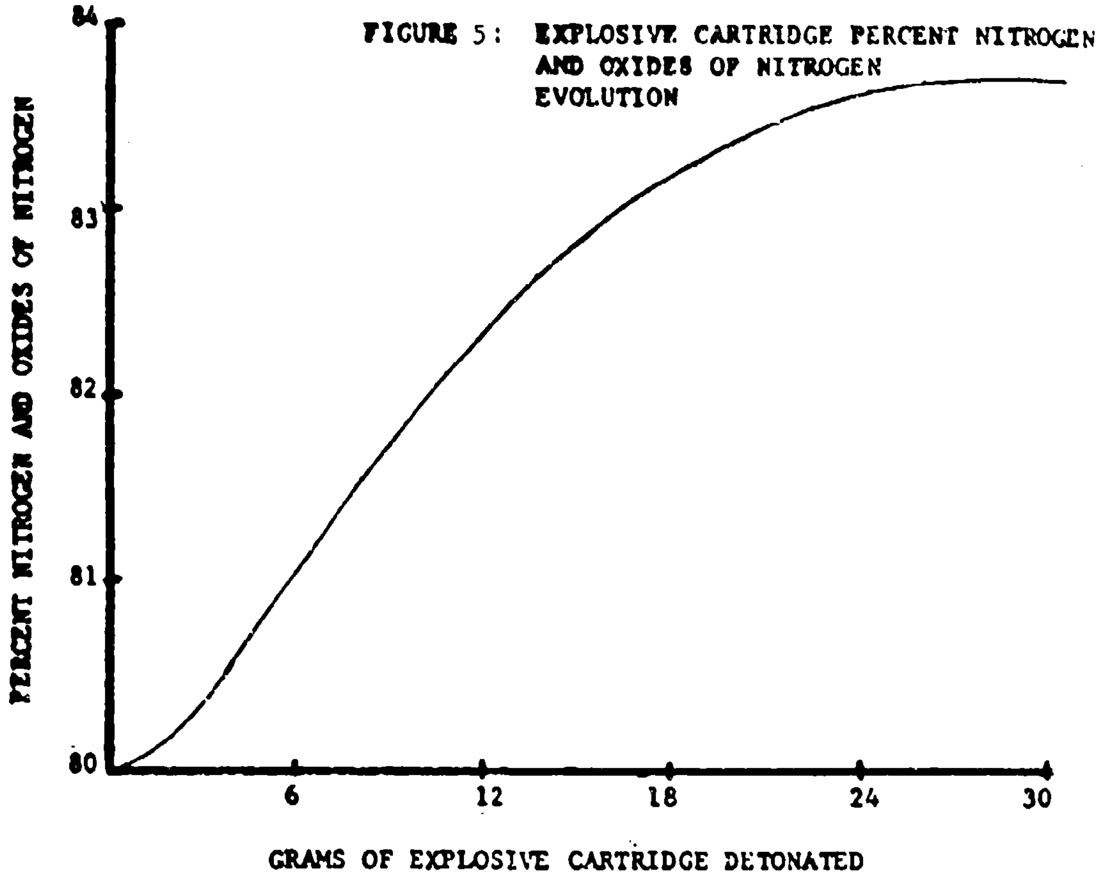


FIGURE 5: EXPLOSIVE CARTRIDGE PERCENT NITROGEN AND OXIDES OF NITROGEN EVOLUTION

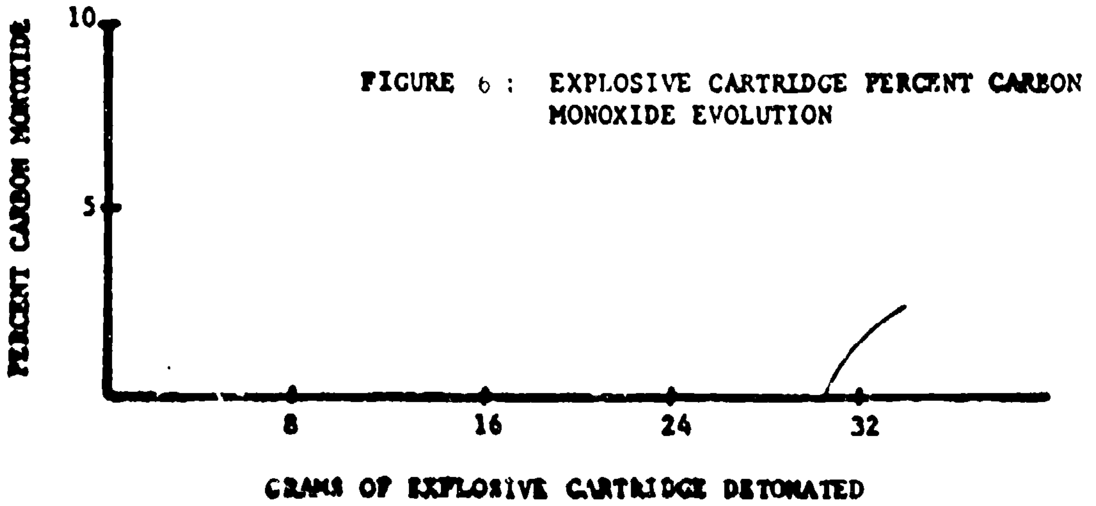


FIGURE 6: EXPLOSIVE CARTRIDGE PERCENT CARBON MONOXIDE EVOLUTION

TABLE III

GAS COMPOSITION CHANGES IN THE EXPLOSIVE CARTRIDGE

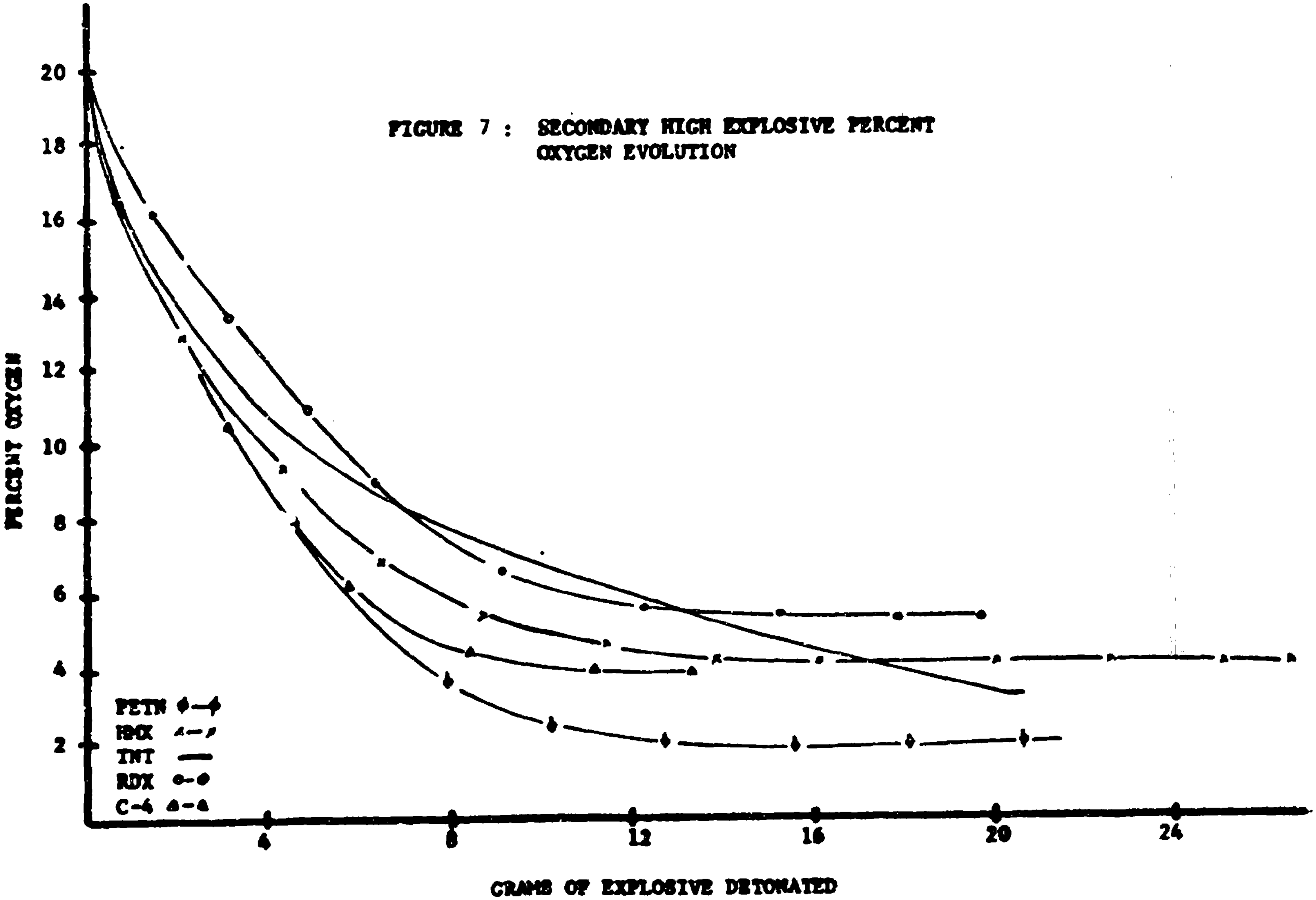
GAS	INITIAL	FINAL	DIFFERENCE
Oxygen	19.7	10.9	8.7
Carbon Dioxide	0.0	5.5	5.5
Carbon Monoxide	0.0	0.0	0.0
Nitrogen/Nitrogen Oxides	80.3	83.6	3.3

TABLE IV

THEORETICAL AND ACTUAL CHAMBER PRESSURES

EXPLOSIVE	THEORETICAL PRESSURE	ACTUAL PRESSURE
TNT (20 grams)	28.63 psia	27.10 psia
HMX (25 grams)	32.93	----
RDX (25 grams)	32.98	----
PETN(22 grams)	25.63	24.00

FIGURE 7 : SECONDARY HIGH EXPLOSIVE PERCENT OXYGEN EVOLUTION



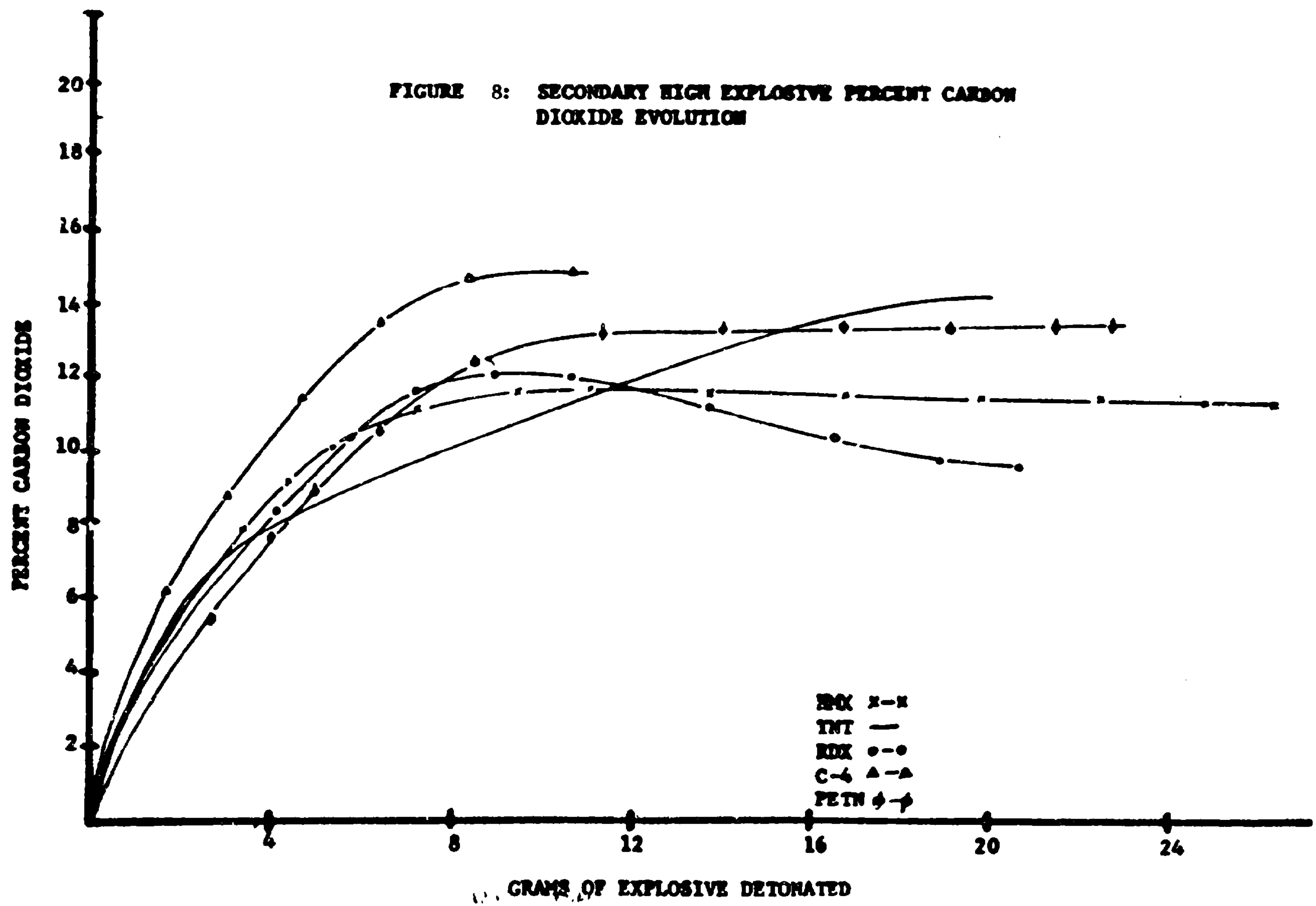
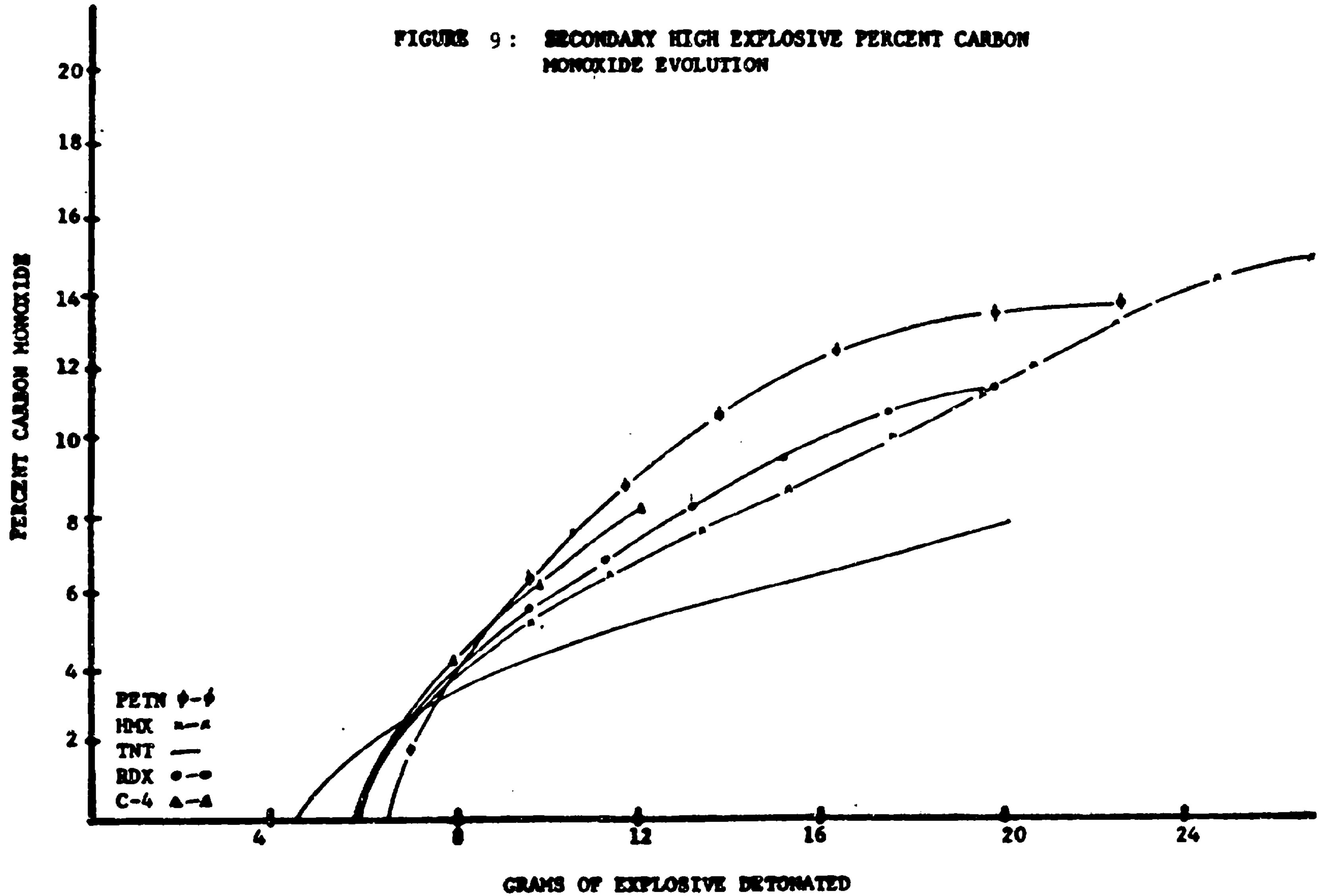


FIGURE 8: SECONDARY HIGH EXPLOSIVE PERCENT CARBON DIOXIDE EVOLUTION

FIGURE 9: SECONDARY HIGH EXPLOSIVE PERCENT CARBON MONOXIDE EVOLUTION



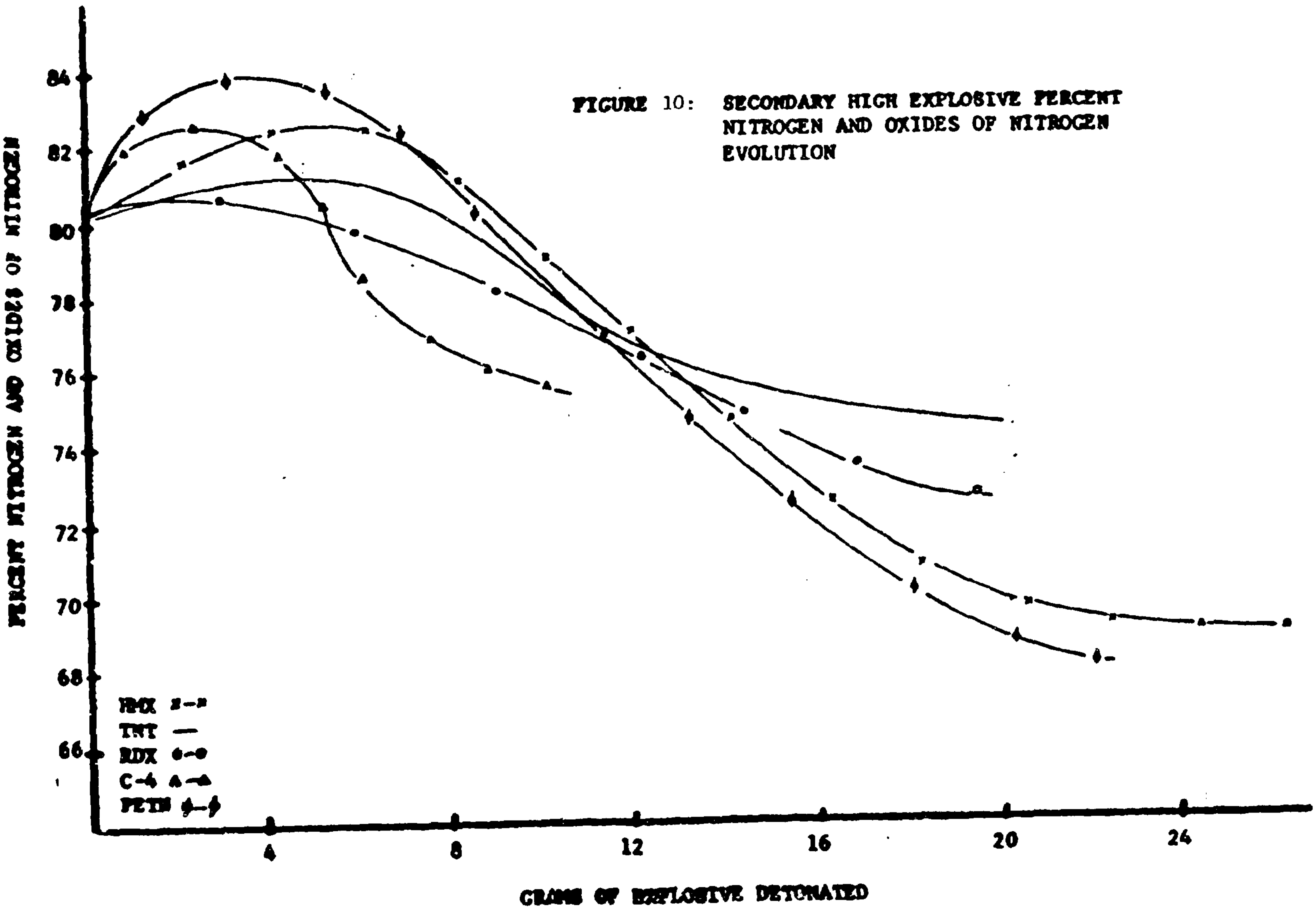


FIGURE 10: SECONDARY HIGH EXPLOSIVE PERCENT NITROGEN AND OXIDES OF NITROGEN EVOLUTION

carbon monoxide appearing after 5-7 grams of explosive were detonated. The gas concentration stabilized at 18-20 grams of explosive detonated and maintained a stability range of 6-15 percent concentration. Figure 10 shows the nitrogen and nitrogen oxides' negative evolution stabilizing at 18-20 grams of explosive detonated and maintaining a stability range of 69-75 percent concentration. No methane nor hydrogen was found during the gas analysis.

Steady-state chamber pressures were measured for some of the high explosives and were compared to the theoretical calculations by the Sinclair-Sewell method [3]. Actual steady-state chamber pressures ran about 5% less than predicted, as shown in Table IV.

Examination of the detonation chamber after each test sequence verified the expected solid carbon and aluminum residue. To determine equilibrium effects, the samples were analyzed at one day, one week, and two weeks after detonation. There were no major changes in the gas composition during a period of two weeks, due partly to "kinetic freeze-out".

The homogeneous solid propellants were then fired in a slightly modified procedure. The gaseous product concentrations exhibited much the same pattern as seen with the secondary high explosives. Figure 11 demonstrates the negative evolution of oxygen stabilizing at 20-25 grams of propellant ignited and a stability range of 2-4 percent concentration. Figure 12 shows the carbon dioxide positive evolution stabilizing at 17-20 grams of propellant ignited and maintaining a stability range of 17-20 percent. Carbon monoxide positive evolution is shown in Figure 13, stabilizing at 25 grams of propellant ignited and maintaining a stability range of 8-14 percent. Propellant 5066 exhibited a small deviation from the rest but

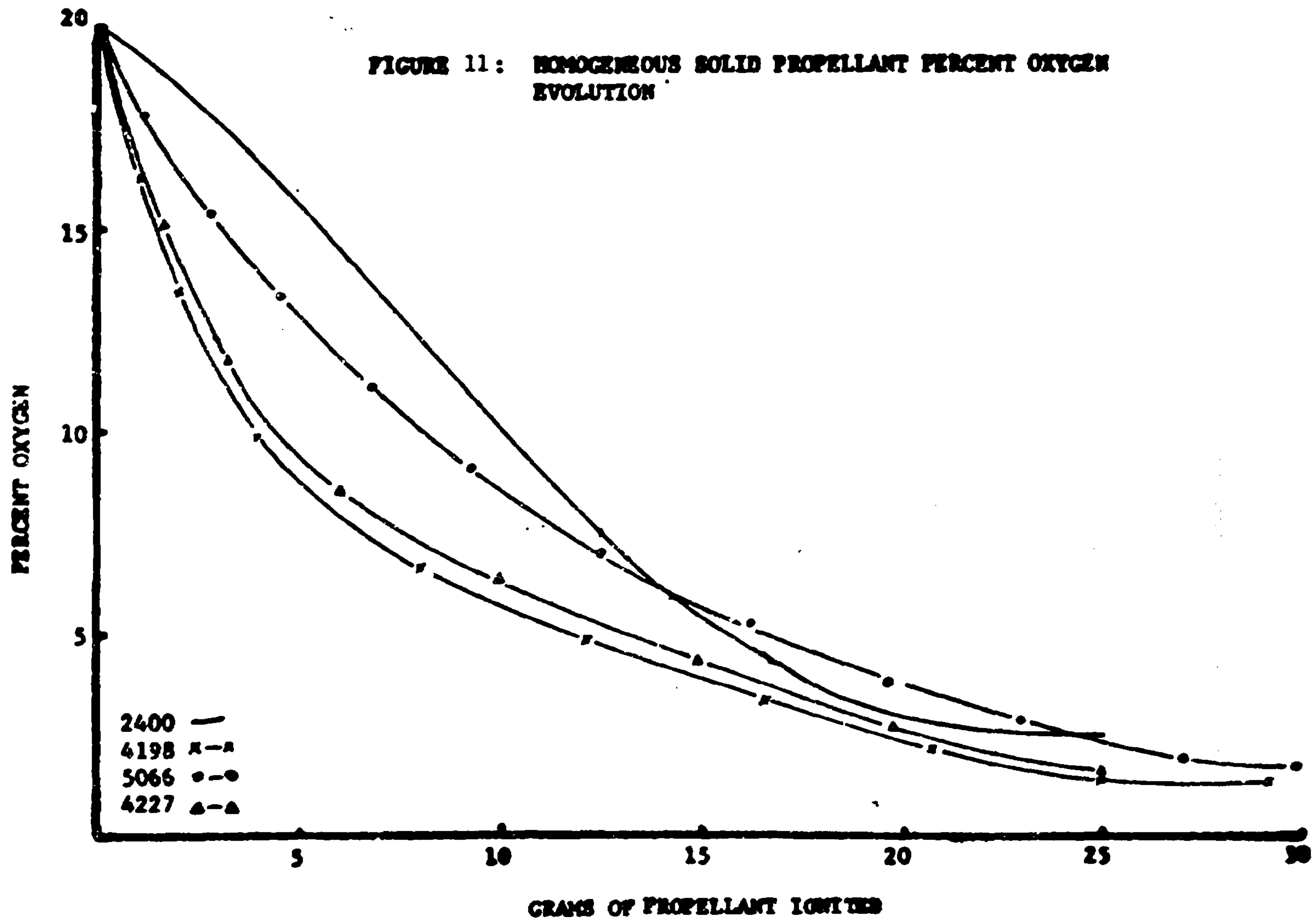


FIGURE 11: HOMOGENEOUS SOLID PROPELLANT PERCENT OXYGEN EVOLUTION

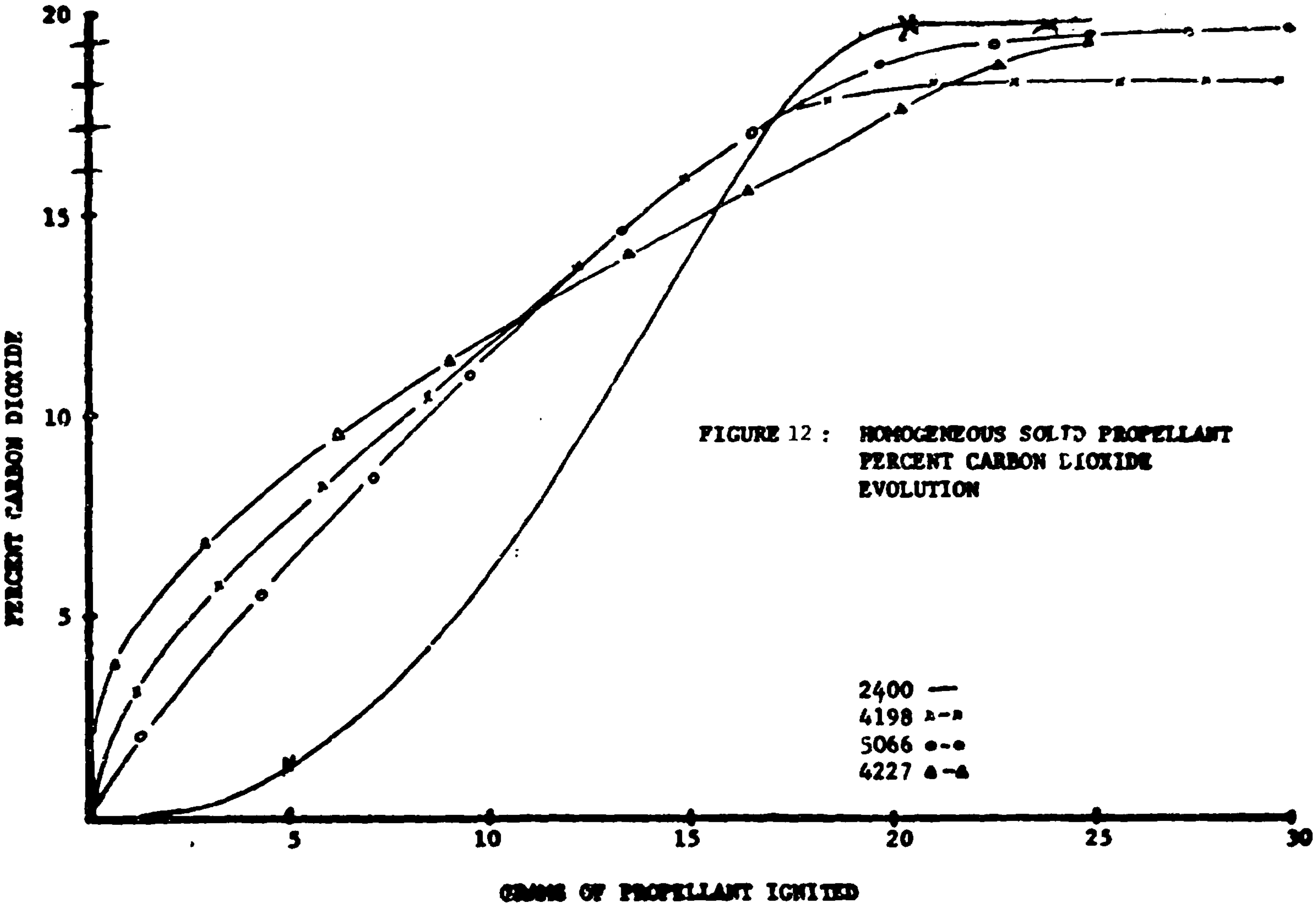


FIGURE 12 : HOMOGENEOUS SOLID PROPELLANT PERCENT CARBON DIOXIDE EVOLUTION

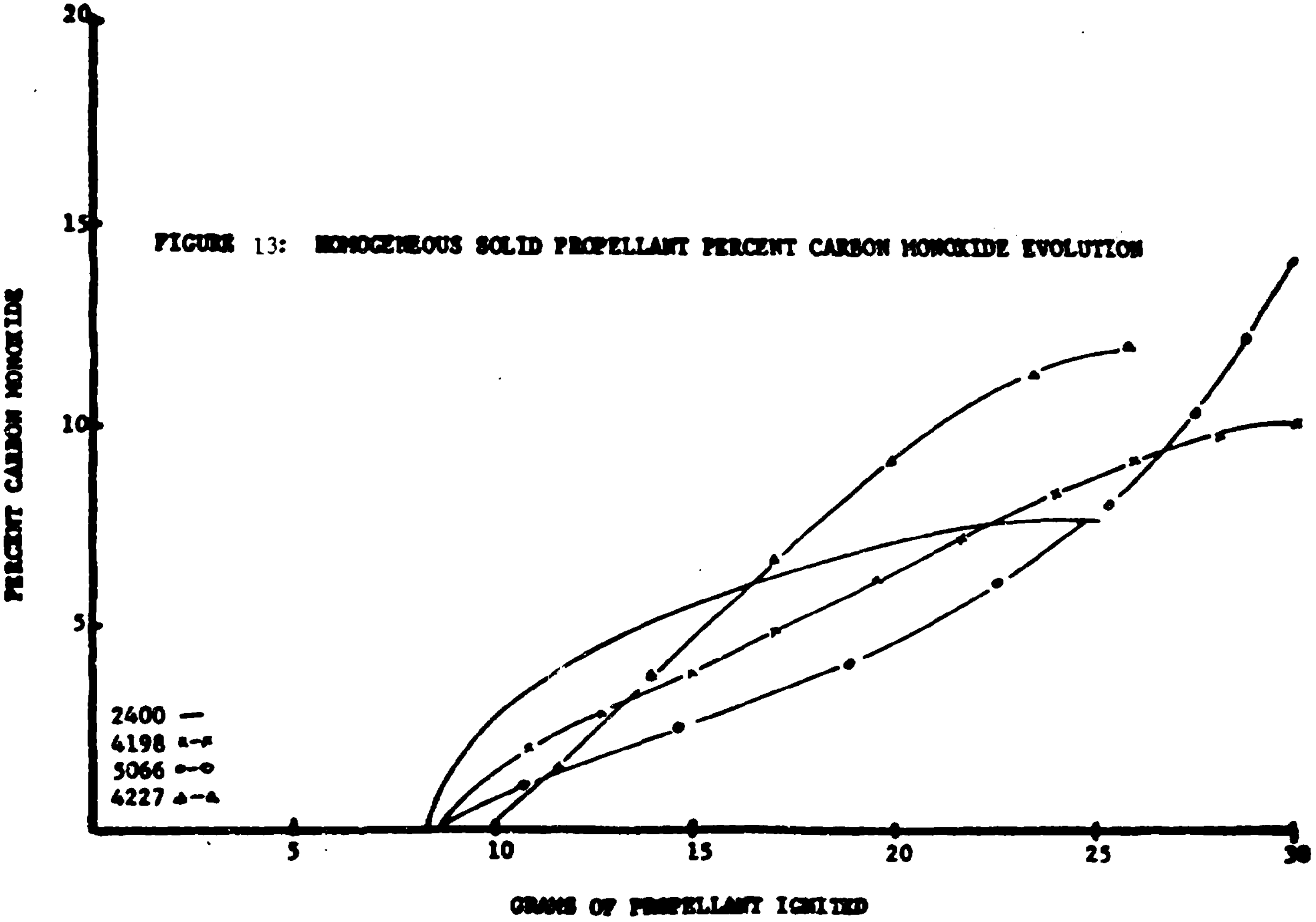


FIGURE 13: HOMOGENEOUS SOLID PROPELLANT PERCENT CARBON MONOXIDE EVOLUTION

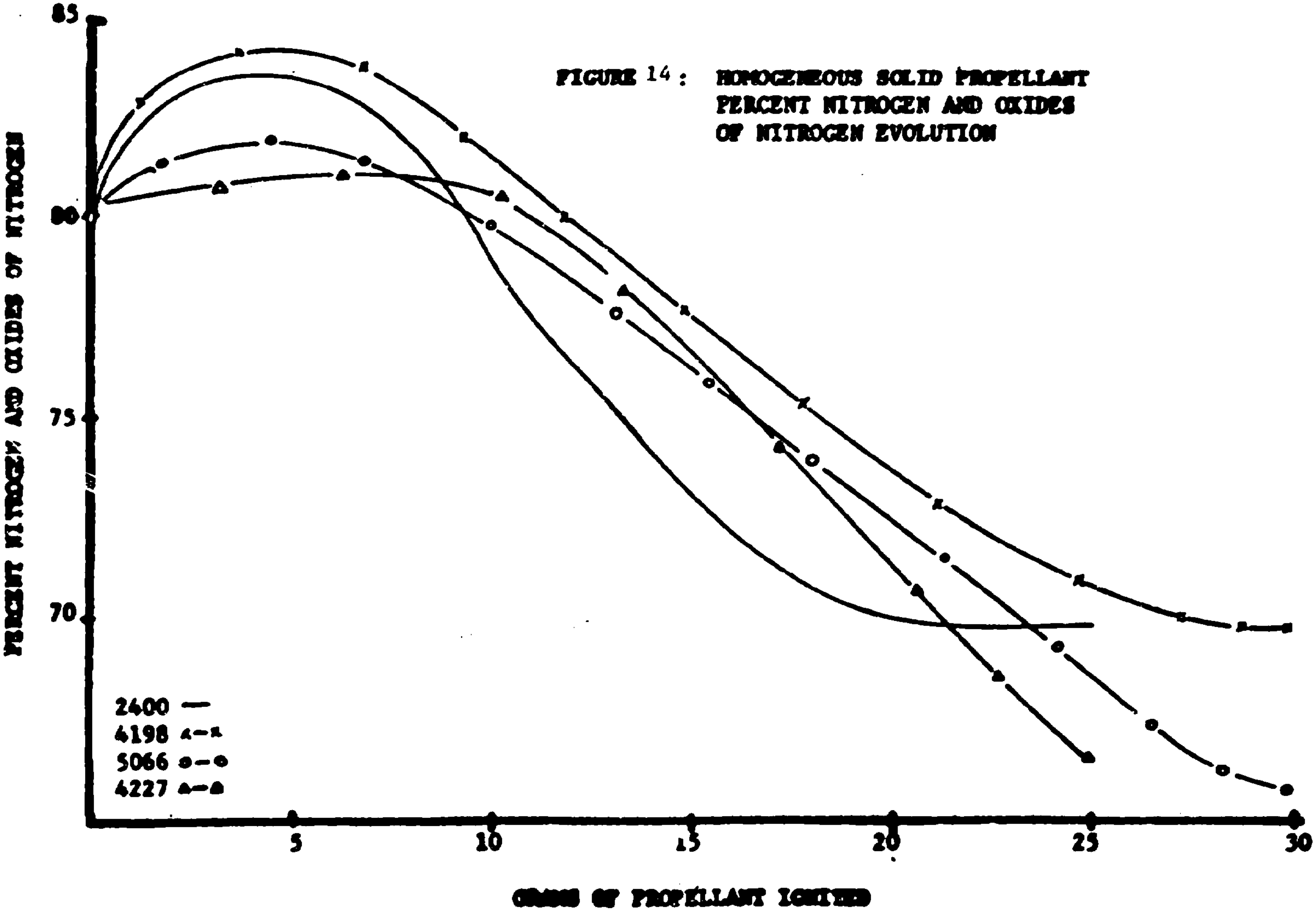


FIGURE 14: HOMOGENEOUS SOLID PROPELLANT PERCENT NITROGEN AND OXIDES OF NITROGEN EVOLUTION

this is thought to be due to its being a double based propellant while the others were single based. Finally, the nitrogen and oxides of nitrogen percentage concentration stabilized at 20-25 grams of propellant ignited and exhibited a stability range of 66-71 percent, as shown in Figure 14. Neither methane nor hydrogen was found during the gas analysis.

Homogeneous solid propellants exhibited the same basic trends as the secondary high explosives, differing only in the exact point of stabilization and the stability range. This is to be expected in view of the different reaction mechanism (deflagration vs. detonation) and different chemical composition.

CONCLUSIONS AND SCALE-UP. The basic research done in this laboratory has shown that, at least in a laboratory scale model disposal chamber, confined chamber disposal is feasible, with predictable gas concentrations and pressures and, therefore, warrants more study. We have shown that for both secondary high explosives and homogeneous solid propellants, the same type of gaseous product evolution is observed even though they are different chemical compositions and operate under different reaction mechanisms. This indicates that the disposal of explosives by the confined chamber method is applicable to both classes of explosives and that the method is, therefore, simplified.

It is felt that with the basic knowledge obtained from this experiment, one could indeed scale up the project while keeping the product concentrations and the static pressures to known levels. Table V shows the volume scale-up that could be used to dispose of larger quantities of explosives without changing the product concentrations or static pressures appreciably from the results of our laboratory model.

TABLE V

ACTUAL CONFINED DISPOSAL SITE PARAMETERS

SITE DIMENSIONS (feet)	SITE VOLUME (cubic feet)	EXPLOSIVE WEIGHT (tons)
10x10x10	1.00×10^{3}	6.38×10^{-3}
50x50x50	1.25×10^{5}	7.97×10^{-1}
100x100x100	1.00×10^{6}	6.38×10^{0}
500x500x500	1.25×10^{8}	7.97×10^{2}
1000x1000x1000	1.00×10^{9}	6.38×10^{3}
130 (diameter sphere)	1.15×10^{6}	7.31×10^{0}
260 (diameter sphere)	9.18×10^{6}	5.85×10^{1}
500 (diameter shpere)	6.53×10^{7}	4.16×10^{2}

Scale-up could be accomplished by using an existing salt mine such as the AEC has used (e.g., the Tatum Dome in Mississippi) or by mining of several facilities across the nation to be used exclusively for explosive disposal. Salt domes have several advantages for this scale-up. First, they are readily available, covering more than one-half million square miles in the United States, as shown in Figure 15. Second, salt deforms quasi-plastically under pressure which allows it to absorb the high stress of cavity opening as well as being self sealing. Under compressive stress, it is impervious to the passage of gases and liquids. Lastly, the technology needed to mine it exists -- one simply solution mines by washing the salt out with water. Figure 16 shows the schematic of a solution mining procedure. [4]

Of the toxic gases present in the chamber, the only ones of environmental consequence are carbon monoxide and the oxides of nitrogen. These would probably have to be scrubbed prior to venting to the atmosphere or perhaps used commercially as starting materials for water gas and nitric acid syntheses, respectively.

Solid products left in the chamber after firing would be carbon, aluminum from the aluminized explosives, and metals used for the casing of ammunition. It is a distinct advantage to retain these products in the chamber as opposed to open burning disposal methods in which these products are significant pollutants. Perhaps reclamation of these products could become economically feasible after many shots, partially paying for the cost of the disposal site. Note that of the twenty largest quantities of AEDA material available for disposal, only 21,717 tons (32%) are explosives and propellants, and 46,586 (68%) are hardware.

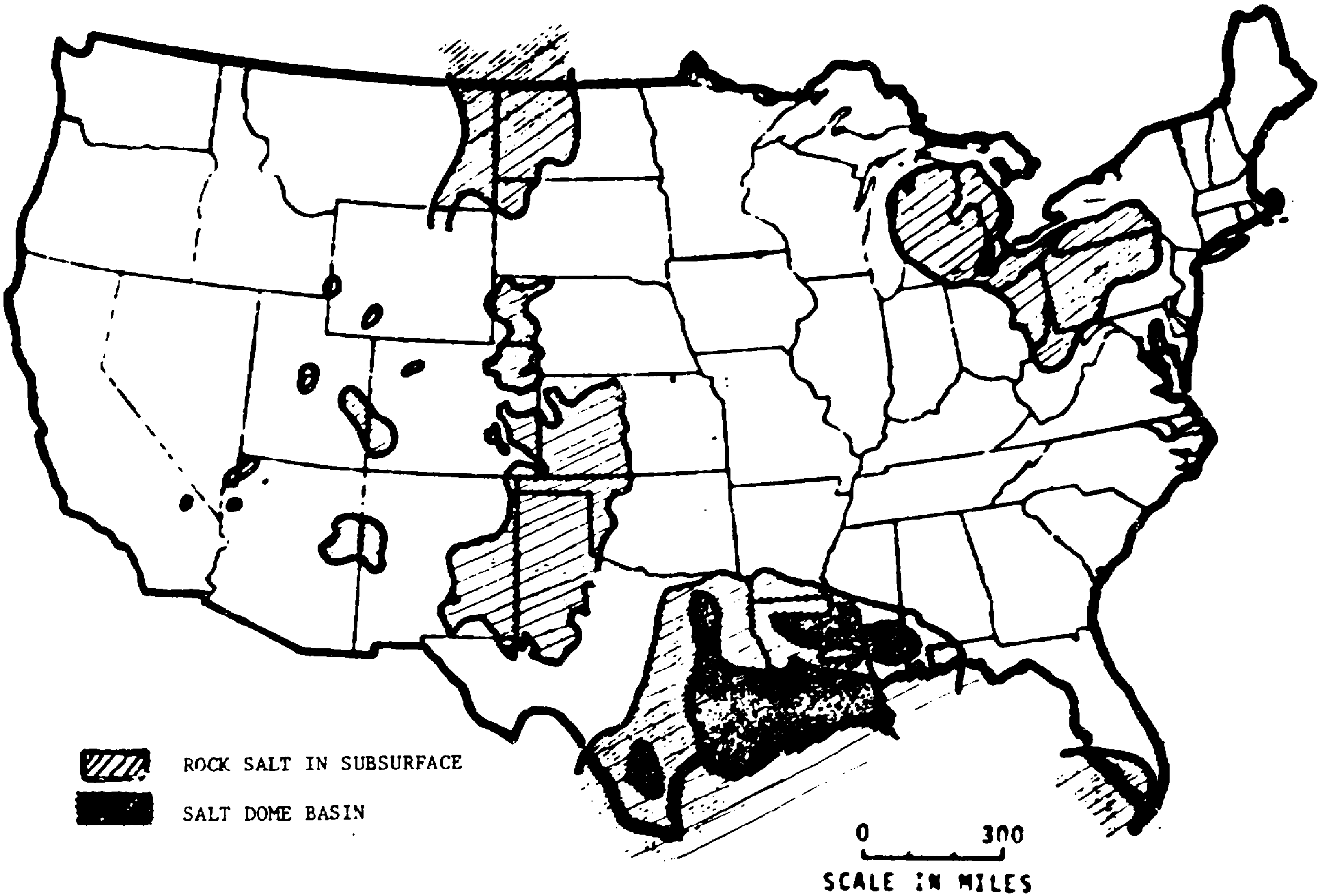


Figure 15: Map of Major U. S. Subsurface Salt Deposits

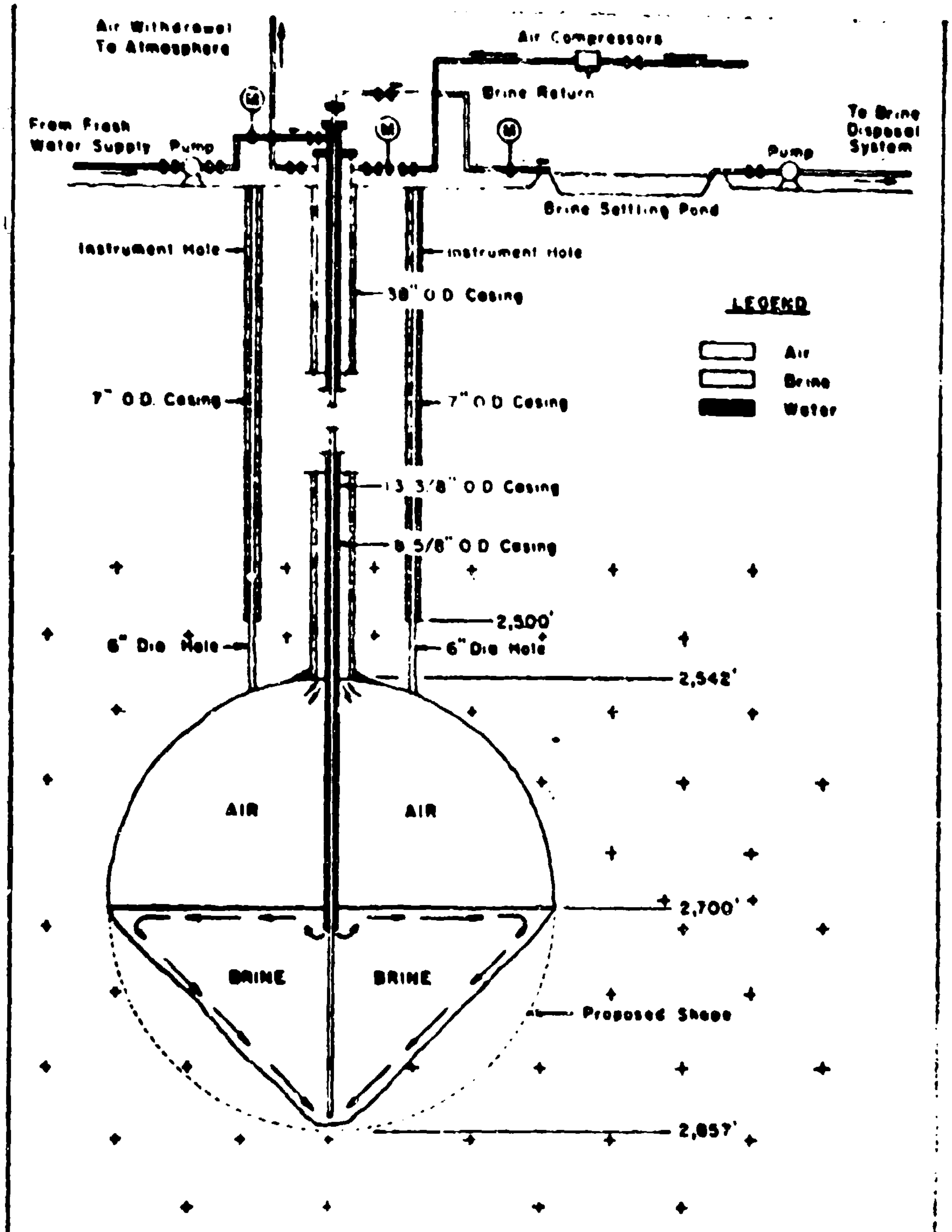


Figure 16

SCHEMATIC FOR THE SOLUTION MINING OF A 315' DIA. SPHERE

RECOMMENDATIONS. It is recommended that a series of full scale tests be conducted in a 10x10x10 foot chamber in salt by detonating 12.76 lbs of TNT to verify the laboratory scaling and product level stabilization. In addition, these studies could be used to study the retention and cleansing effects of the surrounding medium, emplacement techniques, and shock decoupling from the surrounding medium.

Although a cost analysis of this method is beyond the scope of this study, the basic technical research indicates that technology, operational procedures, safety parameters, and physical apparatus are all within the present state-of-the-art and therefore the confined detonation method of excess or waste explosives disposal is an attractive alternative to the explosive disposal problem not only from an environmental impact point of view but from a cost effectiveness standpoint as well.

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CHEMICAL TRAINING FOR EXPLOSIVE ORDNANCE DISPOSAL AND TECHNICAL ESCORT PERSONNEL

MAJ GUY M. LOVELACE, USA
US ARMY MISSILE AND MUNITIONS CENTER AND SCHOOL
REDSTONE ARSENAL, ALABAMA

With the increased public awareness of problems associated with toxic chemical handling and storage, the training of military personnel to work in a toxic environment and to cope with problems related to toxic filled munitions is more important than ever before. Today there is only one service school which prepares Explosive Ordnance Disposal men of all services to work with toxics. That is the US Army Missile and Munitions Center and School, which teaches Phase One (Chemical Phase) of the Explosive Ordnance Disposal Course and the Technical Escort Course. These courses are attended by over 900 Army, Air Force, Navy and Marine students each year and occasionally by allied students and civilians. Following the disestablishment of the US Army Chemical Center and School at Fort McClellan, Alabama in June of this year these courses were moved to their present home at the Missile and Munitions School at Redstone Arsenal. Training has been resumed and eleven classes have graduated to date. The objective of our Phase One Explosive Ordnance Disposal Course is to prepare men of all services to cope with the problems associated with toxic chemical filled munitions, which they may encounter as EOD Technicians. Additionally, we train them to deal with chemical items other than toxics, such as incendiary, smoke and riot control agent filled munitions. We also teach defense against biological attack, biological agent decontamination and munitions disposal for potential enemy items. In accordance with President Nixon's announcement on biological warfare (BW), no offensive use or consideration of BW is taught. There are no US biological weapons, but the EOD man must be able to cope with any munition a future enemy may develop.

In order to prepare our EOD students for these tasks, we give them two weeks of very intensive training. We require a great deal of our students; however, they are well screened before they come to us. They must meet high standards to enter our courses, but ours is a field that does not allow mistakes or second chances. We start them off with eleven hours of classroom instruction on the characteristics of chemical agents and biological defense. Next they receive eight hours on chemical weapons systems where they learn the hardware which may surround the chemical filler. This is followed by classes on the detection and identification of chemical agents and biological agent sampling, as well as individual protective clothing and equipment. The first week concludes with instruction on Hazard Area Evaluation and Leak Sealing and Packaging. Now the student has his theoretical background.

The second week of EOD Phase I is devoted to Practical Exercises. Pending completion of a new training area at Redstone Arsenal, we have a more than adequate temporary site; and we are using simulants that are realistic and give the same chemical reactions with our detector kits. In these exercises, the students will be confronted with active nerve and blister agents. All exercises including toxic agents are conducted under closely controlled environmental conditions and are continuously monitored. After describing the exercises, I will address the safety constraints to which we owe our umblemished safety record. We start the students out with a Round Robin Exercise where they visit a number of stations to observe the detection and decontamination of a series of leaking munitions. This is their first "hot" problem involving active toxic agents or their respective simulants. We contaminate the munitions which they normally fill with a maximum of 20 ml of agent GB, VX, and HD or simulant. The students rotate past each station where they observe the detection of the agent with the M18 Detector Kit and observe the color changes which give them positive identification of the agent. They then neutralize the agent with the most effective decontaminant. Next they prove that the decontamination was complete by retesting and obtaining a negative test. This exercise gives the student several firsts. It is his first opportunity to prove to himself that the protective clothing and mask really do work. It is his first opportunity to see the Detection Devices and Decontaminants actually work on active agents. It is also his first opportunity to prove to himself that he can enter a toxic environment, perform a task, and leave safely without spreading contamination. It should not be surprising that this is also the occasion where some students quit. The EOD student is a volunteer; as such, he has the option to withdraw from volunteer status at any point. Following this first problem where the student becomes familiar with protective clothing and the agents, is a series of three four-hour Practical Exercises in which the students progressively become more skilled in the various tasks to be performed at a chemical accident or incident site. The students rotate tasks in order to perform all the different roles which they may be called upon to play. One role is to act as the man in charge of the Command Post. He logs all actions performed within the exclusion area, predicts the downwind hazard area and stands ready to assist the more encumbered team members on the work party by making calculations and keeping track of time for chemical tests. He may act as the Hot Line Operator and assist personnel entering and leaving the exclusion area. The key roles are those of Team Leader, Reconnaissance Team Member or Work Party Member. These men all enter the contaminated area to reduce and contain the hazard. Prior to graduation, each student has performed every role.

The final exercise of the course is the Disposal Exercise on the next to last day. Here the EOD students terminate their operations by disposing of the munitions similar to those which they have previously identified,

decontaminated and packaged. Currently we stress the neutralization method of disposal since ecological and pollution abatement considerations have made obsolete the prior "open pit burn" methods. At the conclusion of these two weeks of theory and practice, we have a student who knows chemical EOD techniques and, more important, one who has that confidence in his own abilities that comes only from having successfully performed the task in situations that are as realistic as possible. We also give the student the opportunity to demonstrate his knowledge and reenforce his learning by a series of written and performance examinations. To pass the course and continue with his EOD training at the US Navy's Explosive Ordnance Disposal School, Indian Head, Maryland the student must obtain 750 of a possible 1000 points.

The training of Technical Escort personnel follows a pattern similar to that of the EOD student. The objectives are similar; however, the Technical Escort man is as much of an accident preventer as he is an accident responder. His future role will be to accompany shipments of toxic agents to insure their safety. We train the Technical Escort students to know the agents; their detection and decontamination; as well as, the protective clothing in the same series of classes that the EOD students receive. Their course is twice as long and includes a great deal of transportation oriented material. We cover all modes of transportation and the regulatory documents which pertain to the movement of chemical cargos by each mode. Next we give the Technical Escort students a series of eight hour practical exercises in which they act as escort team members in the planning and execution of Road, Rail, Air and Sea Escorts. We insure that each simulated mission encounters a leak or accident which requires them to go through identification, protection, decontamination and packaging steps as did the EOD student. We give them a total of seven active toxic agent exercises and allow them to work on problems with all the environmental constraints which they would encounter in the air, on the road, or at sea. As in EOD, we require the student to make a grade of 750 on our written and performance exams.

While it is necessary for each student to have a firm theoretical foundation for all of his actions, we feel, and our alumni agree that the most valuable part of our courses is our active agent training. The use of active agents in training poses problems as well as paying big dividends in realism. We know that we must use active agents for that essential degree of realism, but we must also protect the student, the instructor and the surrounding population from danger. To provide adequate safety, we use a number of techniques. They include:

1. Limiting the total volume of agent used in the training area by not training more than two classes at one time.

2. Limiting the amount of agent at each incident site at one time.

3. Not utilizing active agents if adequate control and environmental standards such as wind direction, temperature gradient and precipitation are not met.

4. Neutralizing the agent immediately in the event of sudden weather changes or other occurrences.

5. Containing run off of decontaminant agent mixture at the incident site with trenches.

6. The use of gross quantities of decontaminant.

7. Rigid enforcement of a two man rule, i.e. two instructors accompanying each four to six man student group.

8. Dual safety channels - both in the instructional organization and in the student training organization.

9. The use of a'Buddy'system for both students and instructors.

10. Sending our medics through our course.

11. The use of simulants at any time the principal instructor feels it would be unsafe to utilize active agent.

12. The use of a rigidly enforced undressing procedure.

13. The use of highly skilled and dedicated professionals as instructors.

14. The use of a safety officer with each class in the training area.

All of these factors combine to make active agent training both safe and effective.

As was the case in the past our instructors are a joint body, with both US Air Force and US Marine Corps representation on our predominantly Army team. We draw on both the Explosive Ordnance Disposal and the Chemical Career fields for our instructional expertise. Additionally we have instructors who have served in the US Army Technical Escort Center and have logged thousands of miles of safe escort experience.

As a body dedicated to safety, you may rest assured that Explosive Ordnance Disposal and Technical Escort personnel are receiving the best possible technical instruction and practical training that is available anywhere today. These students go to their next assignment knowing that they can perform their chemical disposal or escort mission as they have demonstrated to themselves that they have the skills, knowledge and experience to sustain them at any chemical accident or incident site.

ENVIRONMENTAL EFFECTS OF PAST DEEP WATER DUMPS

LT D. W. Pine, USN
Office of the Oceanographer of the Navy
Alexandria, Va.

From the early 1950's until 1964 obsolete munitions were disposed of primarily by over the side dumping in designated disposal areas. 1964 brought the advent of Operation CHASE (Cut Holes And Sink 'Em). World War II Liberty ships were modified with vents, flood valves and bulkhead cut outs. They were loaded with tons of obsolete munitions, towed out to sea and scuttled. Fifteen of these ships were loaded with conventional munitions, and four contained chemical munitions. Of the 15 conventional ships, 13 detonated enroute to the bottom. Between 1964 and 1970, 19 ships in all were scuttled as part of the program.

In the fall of 1970 the Council on Environmental Quality recommended termination of dumping at sea, and on 7 October 1970, President Nixon stated that he would recommend legislation to stop unregulated use of the sea as a dumping ground. This has since been enacted in the form of Public Law 92-532, the Marine Protection, Research and Sanctuaries Act. Immediately, the Secretary of the Navy placed a moratorium on deep water dump (DWD) operations, which was followed by a Secretary of Defense freeze in April 1971 on ocean dumping of all military munitions by the United States pending the full investigation of all alternative methods of disposal.

The CHASE ships may be separated into two categories: conventional munitions ships and chemical laden ships.

The Chief of Naval Operations in 1971 directed the Oceanographer of the Navy to begin an investigation of the conventional munitions disposal sites. The objectives were:

1. Prepare a comprehensive environmental condition report for representative past explosive ordnance DWD sites.

2. Develop criteria for selection of future sites in the event that DWD is resumed.

3. Determine what monitoring efforts would be required at DWD sites in the future.

In designing the survey program questions foremost in the public mind were considered. The public often views ordnance related operations with an eye to catastrophic possibilities and generally views ocean dumping unfavorably. There has been alarm over possible mass fish kills and the creation of major dead areas on the sea floor. It has been feared that dumping would degrade the ability of the environment to support life and the normal marine food chain. This apprehension dictated that a complete and comprehensive survey program be developed.

An environmental survey is a detailed investigation of the significant organic and inorganic components of an area. The water column cannot be investigated without considering the sediments over which the water flows. In consonance with this one cannot characterize the animal life without first understanding the quality of the water and the sediment. The sampling program becomes increasingly interrelated. The final evaluation is the comparison of the characteristics of the test site with the stable, unchanged characteristics of a control site. Frequently, one can enter previous literature for the control comparison, thus avoiding the requirement of two exhaustive environmental surveys, one at the test site and one at the control site. Unfortunately, complete benthic surveys and comprehensive literature did not exist to which our deep ocean environmental survey could be compared. Therefore, the survey became a project of extensive detail and magnitude.

Several Navy operational and staff commands, three Navy laboratories, scientists from three major universities and representatives of the National Academies of Sciences and Engineering participated in the selection of two representative DWD sites. Senior credentialed researchers from the fields of chemistry, biology, physics and geology participated in the design of a creditable sampling program and then executed the plan.

The representative dump sites were one site for detonated cargo and one for an intact hulk. In the area off Cape Flatterv, Washington, five ships were sunk and exploded in 8,400 feet of water. In the area southeast of Charleston, South Carolina, one intact ship was sunk in 6,300 feet of water.

In order to be successful in this program the precise location of the hulks was required -- no small task in water a mile and a half deep. A search phase to locate the hulk was developed, and then a follow-on environmental survey for each site was planned. The search phase was controlled by a satellite navigational system which provided an accuracy to within one-tenth of a mile.

The search operations phase in the area off Cape Flattery was conducted by Scripps Institution of Oceanography from the USNS DE STEIGUER. Debris from all five hulks was located. Side looking sonar showed the debris patches to be nearly circular in shape with an average diameter of 550 yeards. The hulks and cargos had been reduced to rubble by the detonations. No cratering of the sea floor was detected. Many types of bottom organisms were observed within and outside the debris fields. The conditions at the bottom were photographically recorded.

Once the debris fields were precisely located, the Naval Oceanographic Office coordinated the follow-on environmental investigation. Data were collected for analyses of sediment properties, water mass characteristics, circulation dynamics, levels of possible heavy metals and explosive residues, and bottom biological populations. The data collected were compared to similar data collected at reference stations outside the dump areas. Current meter arrays and radon measurements were conducted to evaluate the horizontal and vertical circulation dynamics in the area.

In the sediments at the detonated cargo site no anomalies were detected in the level of organic carbon and organic nitrogen -- components of explosive residues. This would indicate no biological uptake of detonation by-products. All mineralogical and physical properties were within ranges previously reported in scientific literature. Water mass characteristics and nutrient levels were also within the envelopes of values found in the literature.

Bottom currents were measured with a bottom current meter array, and the currents encountered were considered sufficient to insure dispersion if any explosive products were generated by the debris fields. There also is a stable layer at 60 - 80 meters above the bottom. Therefore, had there been any contamination resulting from residues in the area, these contaminants would essentially be confined to the bottom 80 meters of the water column and would not interact with the surface food chain in that area. Bottom fauna analyses correlated to historical data and control site values.

In the analyses of explosives components and residues in sediment, benthic fauna and near bottom water, the limits of analytical detection for TNT, RDX, and tetryl were at the level of a few parts per trillion for sea water and several parts per million for sediment and faunal samples. The analyses of the samples showed no evidence of contamination. The same can be reported for the lead and mercury investigations.

The second conventional dumping site surveyed, which is located off the East Coast near Charleston, was the representative site for undetonated cargos. The USNS MIZAR from the Naval Research Laboratory identified the hulk area, and conducted an environmental survey similar to that conducted off the West Coast. The primary search area was covered by a deep towed, side-look sonar, magnetometer and cameras until a search effectiveness probability of 99% was attained. Although several magnetic contacts were made, no photographs of the intact hulk were obtained. Bottom trawls did recover barnacle encrusted ships' hull type steel, and the barnacles were shallow water dwellers. This would indicate that the steel may have been part of the CHASE ship. Search photography did locate scattered ordnance and ordnance-related debris on the sea floor. The area had, in addition to DWD, been used as an over-the-side disposal site prior to the CHASE scuttling. Although the hulk was not photographically located, it is considered a valid assumption that the area is representative of a dump site for unexploded munitions and that our investigations were very close to the hulk itself. Biological, sedimentary and water mass investigations were then conducted in this area in a manner similar to that on the West Coast. Again, as at the site for detonated cargos, the biological, sedimentary, and water mass characteristics reflected no detectable contamination from conventional munitions DWD operations. These investigations at the conventional munitions DWD sites were published in the U. S. Navy Environmental Condition Report for Numbered Deep Water Munitions Dump Sites.

Of the 19 CHASE operations, there were only four CHASE ships with chemical munitions -- yet these four managed to capture the public's imagination. A second report, the Department of the Navy Environmental Condition Report for Deep Water Dump Area A, addresses a chemical munitions dump site.

CHASE disposal operations were still in progress when the first survey was conducted at a chemical DWD site. In 1969, a year before the Secretary of the Navy DWD moratorium, a preliminary survey was conducted at CHASE disposal site A, located 152 nautical miles east southeast of New York City on the Continental Slope in 7,000 feet of water. Hulls numbered 8, 11, and 12 were here. The ships contained GB, VX and Mustard. An extensive follow-on survey was conducted in 1972 on CHASE hulls 8 and 11.

Again, as in the conventional munitions survey, the two phase technique was employed: phase one -- locate and identify and hulks; phase two -- conduct environmental sampling at the site.

Once again, since comprehensive historical background data was not available, control sites were established several miles away from the dump site for comparisons of sediment, water mass, circulation dynamics, levels of contaminants and biological samples.

Thousands of photographs were sorted and inspected. From these, statistical population estimates were developed. During the 1969 preliminary survey, photographs revealed a considerable number of dead sea urchins. The frequency of dead individuals within the urchin population at the dump site was believed to be abnormally large. With this 1969 data in mind, particular attention was paid to the urchin population in the 1972 investigation. Extensive photographic and statistical comparisons have since shown that the ratio of living to dead urchins at the control and at the dump site is not abnormal and the urchin population is coming along in fine sea urchin style. Apparently the skeletons of dead urchins persist for long periods of time at great depths, thus cluttering the area with skeletons and leaving the impression of widespread mortality.

In summary:

1. The two heavily laden hulks are intact and have had no catastrophic effect upon the environment.

2. Water samples taken near the hulks show no leakage and no presence of chemical agents.

3. However, if leakage should occur, the material would be hydrolized and would be entrained in stable bottom water layers.

While it is recognized that all questions about the environmental effects of past DWD operations could not be answered by these recent investigations, the results of the parameters investigated indicate that other than sea floor litter, the deep water disposal method for chemical and conventional munitions does not produce significant irreversible long term damage to the deep ocean environment.

DESIGN OF A BUILDING WALL SUBJECT TO BLAST LOADING

C. F. Baker and R. K. Mullins
Lawrence Livermore Laboratory, UnivCal, Livermore, Calif.

ABSTRACT

This report demonstrates a method used to modify a building wall which is subject to blast loading. The design blast load was determined by scale-model testing. A computer program is devised to predict the behavior of the single degree-of-freedom structure. The existing wall is seen to be inadequate and a new wall is designed. The existing and new wall designs are tested to check the design calculations. The tests agree reasonably well with design calculations and the new wall is shown to be adequate.

INTRODUCTION

Building 816 is a high-explosive machining facility which has provisions for remote control operations. The sensitivity of the explosive and type of machining performed are factors in determining whether or not to operate remotely.

A question was raised as to how much high explosive could be remotely machined safely in the machine bay adjacent to the control room. It was assumed that the existing reinforced concrete structure with compacted earth fill separation would be adequate, with the possible exception of the asbestos cement panel end wall. If the structural integrity of the asbestos cement wall could be maintained then overpressures would not be a problem.

When high explosives are detonated, the surrounding structural elements are subject to a pressure-time loading. The loading is primarily governed by the weight of the explosive, distance of the explosive from the structure, and geometry of the explosion site. A pressure-time history can normally be determined from curves which give maximum peak or reflected overpressures, arrival times, duration times, etc. These results are for "normal" geometries and are usually accurate to within 10%, as observed in previous testing. Explosive equivalency factors can be applied to these curves which are based on TNT. In our case, PBX-9404 high explosive is used. Since the wall in question is separated from the shot by the intervening control room and the curve results could not be directly applied, it was necessary to determine the pressure-time history by scale-model testing.

Elastic load curves were used in the final wall design. This is appropriate since asbestos cement is a very brittle material with an estimated ductility factor of 1.1 to 1.2.

Figure 1 shows the layout of Building 816. It is desirable to have a safe high-explosive machining weight limit of 300 lb in Room 134. During remote machining, Control Room 145 is inhabited.

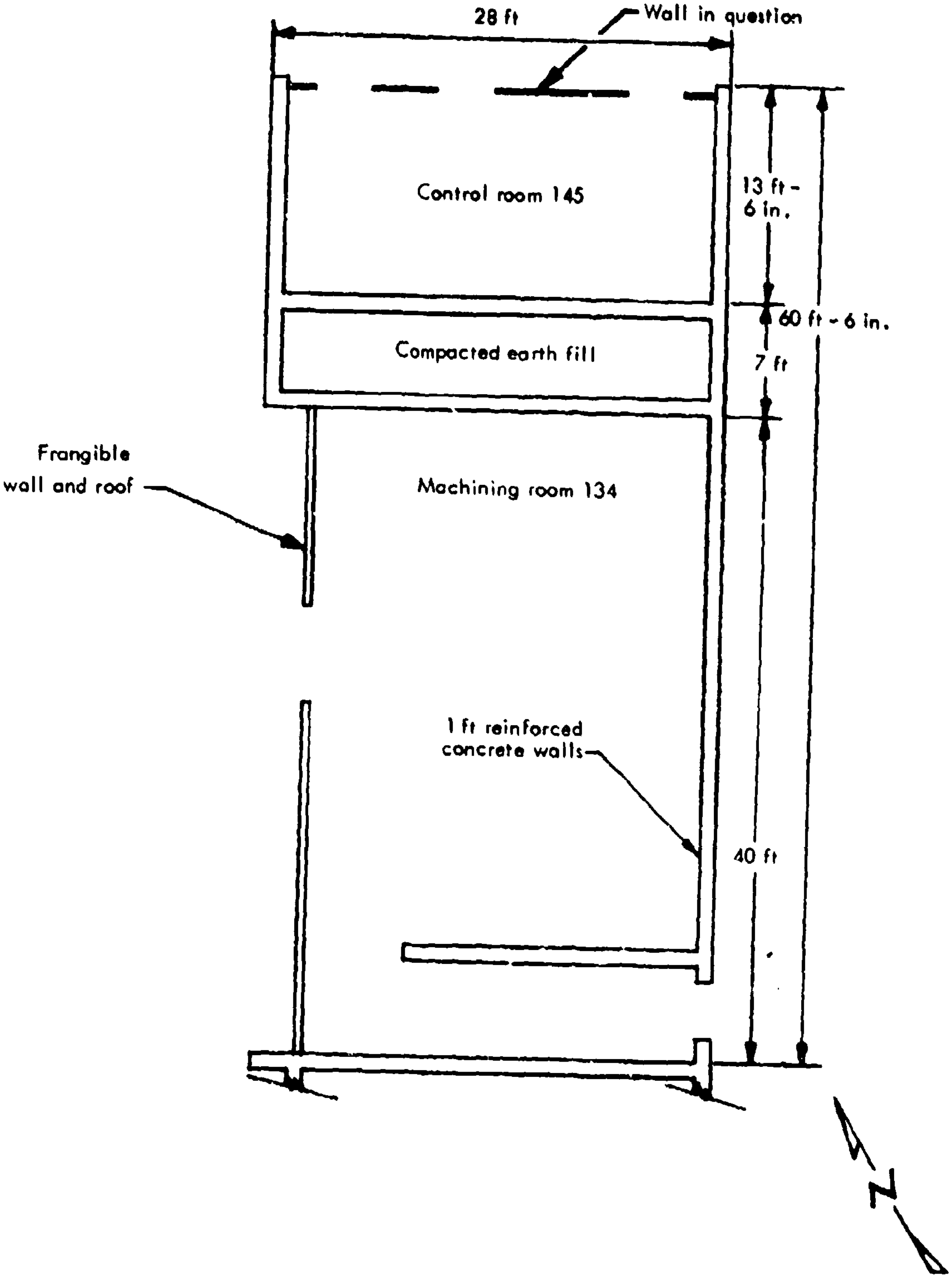


Fig. 1. Existing Bldg. 816 plan – north end.

The control room is protected by 1-ft-thick reinforced concrete walls and ceiling with a 7-ft-high reinforced concrete wall and earth fill barricade separating machine and control rooms. The north wall is constructed of 1-1/8 in. asbestos cement building panels with a maximum span of 47 in., supported by wood studs.

Asbestos cement panels were considered for the modification because of low installation and maintenance costs.

SCALE-MODEL TESTS

Scale Model

A one-quarter scale steel plate model (Fig. 2) was constructed to represent the machining and control rooms at Building 816. Some minor failure occurred in the model during the last shot, but did not seem to affect the test results.

Testing Procedure

After two preliminary shots in which errors due to scope failure and improper mounting occurred, four test shots were performed.

Gauges consisted of a lead "pig" with a piezoelectric pressure-sensing cell* located in the tapered nose of the pig. The gauges were isolated structurally from the blast structure and mounted in sandbags (see Fig. 3). Table 1 is a summary of the test data.

Scaling Procedure

Charges were selected from available prepared 9404 high-explosive spherical charges with a center detonator. Charge size was based on the charge distance relationship, $Z = \frac{r}{W^{1/3}}$ where

Z = scaled distance, in. ft/lb$^{1/3}$,
r = radial distance from charge, in feet (for the scale model, r = 11 ft),
W = charge weight, in pounds.

$$Z \text{ model} = Z \text{ prototype} = \frac{11}{1.26} = 8.7 \text{ (for 2 lb)}$$

$$= \frac{11}{1.59} = 6.9 \text{ (for 4 lb)}$$

*Kistler Corporation Model 606A. Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Atomic Energy Commission to the exclusion of others that may be suitable.

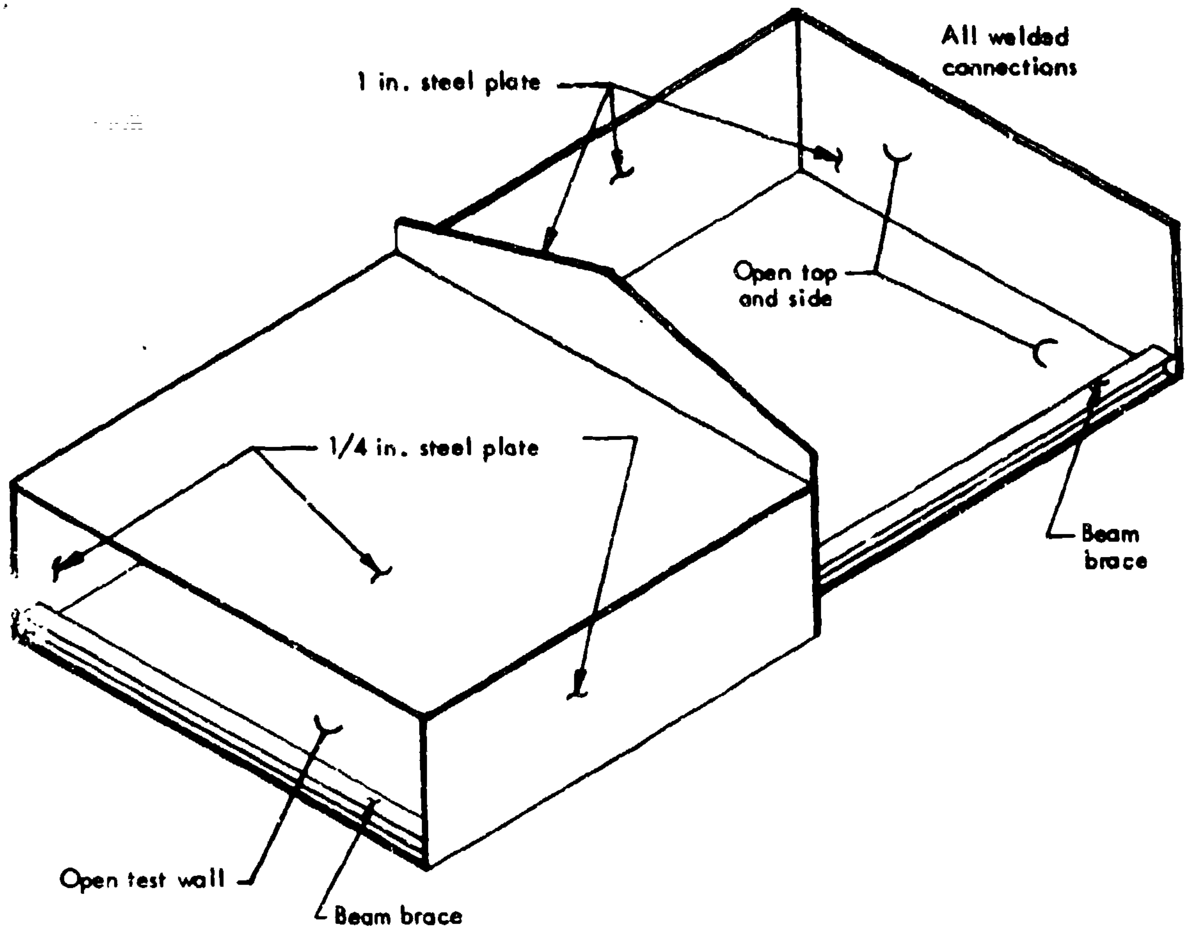


Fig. 2. Steel plate model.

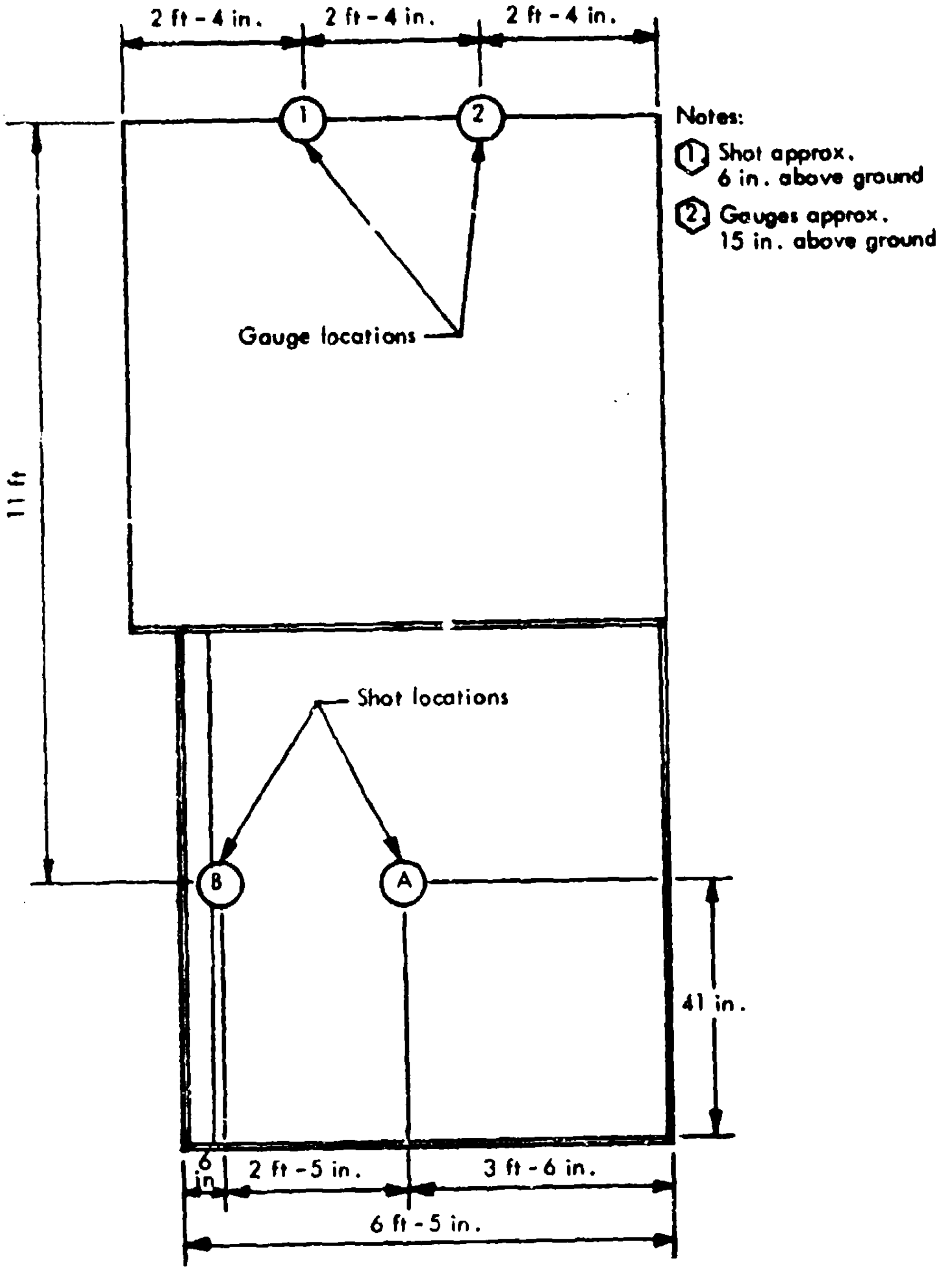


Fig. 3. Shot and gauge locations.

Equivalent charge weight:

$$\left[\frac{W\ (\text{prototype})}{(\text{scaling factor})^3}\right] = W \text{ test charge;}$$

for 4 lb, W (prototype) = 256 lb and
for 2 lb, W (prototype) = 128 lb.

Table 1. Summary of test data.

Shot No.	Wt HE (lb)	Location	Approx straight line dist.	Calc pressure expected,[a] PSO (psi)	Actual av max pressure, P_{SO} (psi)	Scaled, distance, Z	Av max positive pulse duration, to (msec)	Av positive impulse, I_s (Area under curve) (psi-msec)
101	2	A	11	13.4	2.1	8.7	6.1	7.0
109	2	B	11	13.4	2.3	8.7	5.2	7.1
128	4	B	11	21.5	3.5	6.9	6.0	11.1
126	4	A	11	21.5	3.3	6.9	5.7	11.0

[a]Using "Pete's Blast Characteristics"[1] with no allowance for geometry. Spherical charge at sea level — surface explosion. 11% increase for use of 9404 explosive (see also Ref. 6, pp. 4-8). This initial pressure was calculated for the purpose of determining the instrument range. It was recognized that there would be some geometry attenuation.

IMPULSE MOMENTUM THEORY

From preceding test results, we have determined a typical pressure-time history (Fig. 4) for a particular charge weight and structure-charge geometry. It is now necessary to relate these results to a particular loading condition so that the structure (in this case the asbestos cement wall) can be analyzed.

The structural response to any loading condition is not instantaneous; it requires a finite period of time for a member to respond to a superimposed load. If the duration of the load is short compared with the natural period of the structure, the load may be considered to be an impulse which represents an amount of energy that must be absorbed by the structure.[2]

For a decaying type of loading condition such as a shock wave, it can be clearly seen that a member may never reflect the maximum dynamic load. In most cases, the dynamic load is complete before the member fully responds. On this hypothesis, the following analysis is based.

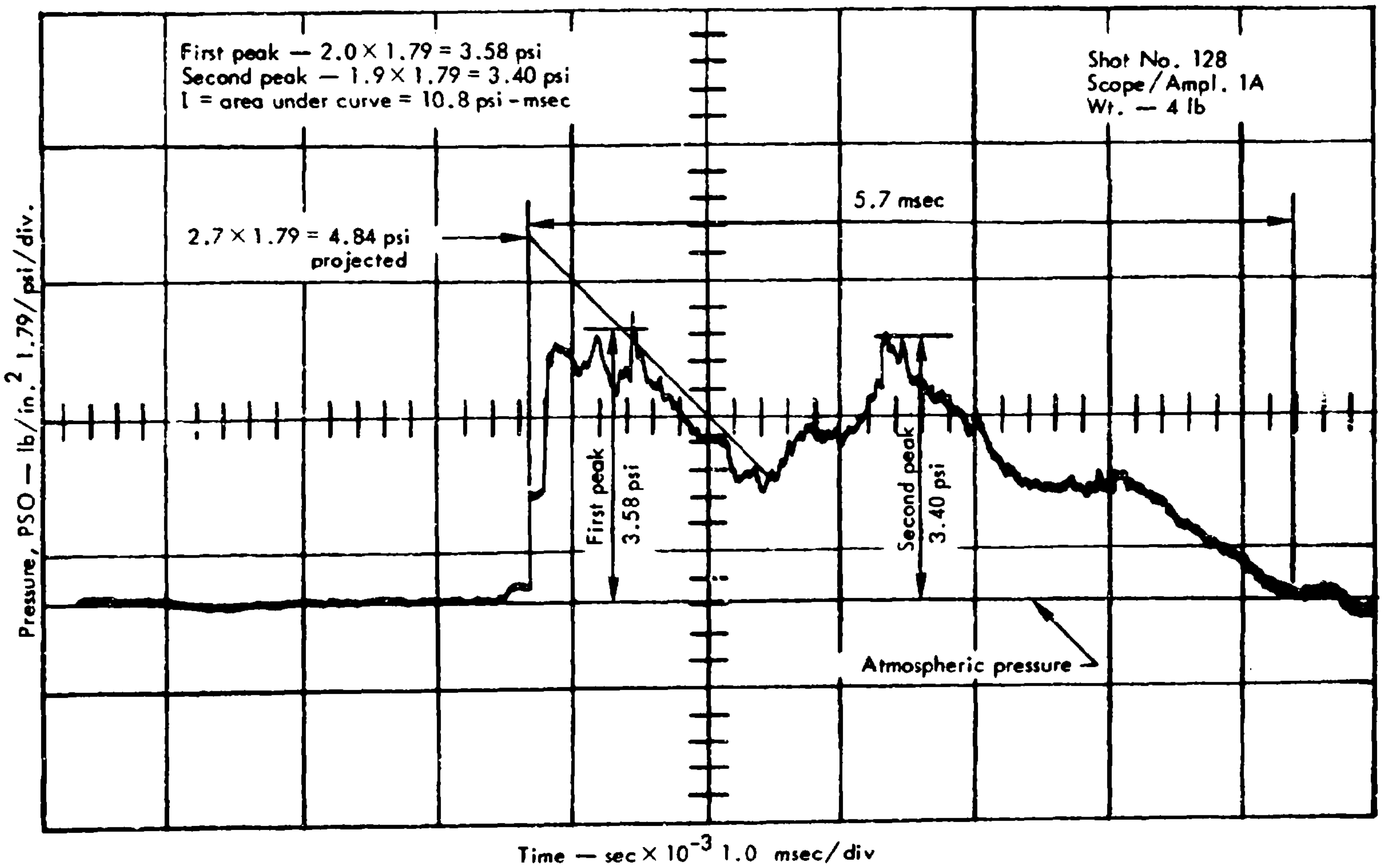


Fig. 4. Typical pressure-time curve.

Spring Analogy

Almost every structure can be represented by the simplo spring mass system. If F is the force on the spring and K is the spring constant, then by Hooke's Law $F = KX$, with X being the displacement of the appropriate units.

Equations of Motion

$$X = \int V\, dt \qquad V = \int a\, dt \qquad X = \int\left[\int a\, dt\right] dt.$$

If velocity at time n is known,

$$V_{n+1} = V_n + \int_{t_n}^{t_{n+1}} a_{(t)}\, dt. \tag{1}$$

If displacement at time n is known,

$$X_{n+1} = X_n + V_n\left[t_{n+1} - t_n\right] + \int_{t_n}^{t_{n+1}}\left[\int_{t_n}^{t_{n+1}} a_{(t)}\, dt\right] dt. \tag{2}$$

If we assume a varies as a straight line between t_n and t_{n+1}

$$a_{(t)} = a_n + \frac{a_{n+1} - a_n}{\Delta t_n}(t - t_n). \tag{3}$$

Substituting (3) into (1),

$$V_{n+1} = V_n + \frac{a_n}{2}\Delta t + \frac{a_{n+1}}{2}\Delta t. \tag{4}$$

Substituting (3) into (2),

$$X_{n+1} = X_n + V_n\Delta t + \frac{a_n}{3}\Delta t^2 + \frac{a_{n+1}}{6}\Delta t^2. \tag{5}$$

Since $F = ma$, then for the simple spring mass system

$$a = \frac{P - R}{m}, \tag{6}$$

where

a = acceleration, in./sec^2;

P = force applied to the structure in pounds, from the dynamic load;

R = the resistance of the "spring" (KX), in pounds; and

m = mass of the system (lb-sec^2/in.).

Using an iteration process involving Eqs. (4), (5) and (6), a maximum deflection can be calculated. The location of the maximum deflection depends on support and load conditions, but in the case of a simple beam uniformly loaded it would occur at midspan.

COMPUTER PROGRAM

A computer program was developed by Steve Szybalski and Hews McCann of LLL Plant Engineering as a solution to the time-consuming iteration process involved when solving for the maximum structure deflection.

Data Input

Data input for the program is as follows:

1. Initial force (pounds) on the structure. This is the ordinate of the pressure-time curve.
2. Weight of structure (pounds).
3. Spring constant of structure (pounds of force required to cause a 1-in. deflection).
4. Positive pulse duration (milliseconds). This is the abscissa of the pressure-time curve.
5. Total time for which results are needed (seconds). At least one-fourth of natural period of the structure is needed for maximum deflection.
6. Time increment of calculation, t (seconds). This will normally be some integer of the positive pulse duration.

Printout

Acceleration, velocity and deflection for each increment of time are printed out, as well as a plot of each of the variables versus time.

Assumptions

A triangular approximation of the pressure-time curve is made to satisfy programming.

IMPULSE THEORY

Impulse Versus Maximum Pressure

During previous explosive testing at Site 300, notably glass breakage tests, it has been demonstrated that structural failure is influenced by both impulse and pressure.

A detailed examination of the two conventional criteria for blast damage potential reveals that the peak overpressure criterion is deficient in that it predicts a damage capability that is the same both for very short disturbances and for sustained high pressures, provided only that the peak values are the same. Likewise, the impulse criterion is deficient in that it considers as damaging those small and actually undamaging overpressures that are applied over a long period of time.[1]

Calculations

To relate results of our scale-model tests to the real case, it is necessary to convert results to 300 lb of 9404 high explosive.

Pressure:

From Ref. 1, pp. 317-338,

$$\frac{300 \text{ lb}}{(\text{scale factor})^3} = \frac{300 \text{ lb}}{(4)^3} = 4.69 \text{ lb equivalent HE (scale factor} = 4).$$

From Table 2,

$$R_p \text{ Avg.} = 30.26 \text{ ft} - \text{for } 300 \text{ lb } Z_p = \frac{R_p}{(W)^{1/3}} = \frac{30.26}{(4.69)^{1/3}} = 18.1$$

From Ref. 3, pp. 4-8,

P_{S_0} = 3.5-psi expected pressure from 300 lb of 9404 at full scale.

Impulse:

$$\frac{I_1}{W^{1/3}} = \text{Constant} = K$$

$$I_1 = KW_1^{1/3}$$

$$I_2 = KW_2^{1/3}$$

$$I_2 = K\,(n^3W_1)^{1/3} \text{ and } W_2 = n^3W_1$$

$$I_2 = Kn\,W_1^{1/3}$$

$$I_2 = nI_1$$

where I_1 = test impulse,
I_2 = design impulse,
W_1 = test charge,
W_2 = design charge,
n = scale factor.

Impulse:

From Table 2,

$$R_I \text{ Avg.} = 22.85 \text{ ft},$$

$$Z_I = \frac{22.85}{W^{1/3}} = \frac{22.85}{(4.69)^{1/3}} = 13.69,$$

$$\frac{{}^*I_s}{W^{1/3}} = 7.4, \qquad I_s = (7.4)\ (1.67) = \underline{12.36 \text{ psi-msec}}\ (n = 4).$$

Since $I_2 = nI$, then I_s for 300 lb = nI_s for 4.7 lb.

$I_s = 4 \times 12.36 = 49.4$ psi-msec impulse expected from 300 lb of 9404 at full scale.

Time:

From Table 2,

$$R_t = 46.2 \text{ ft}.$$

Only results from shots 109 and 128 were used in this average since the other two data points on each end were extreme. Since graphical methods were used to obtain these results, this variance was not unexpected.

$$Z_t = \frac{46.2}{(W)^{1/3}} = \frac{46.2}{(4.69)^{1/3}} = 27.7,$$

$$\frac{{}^*t_o}{(W)^{1/3}} = 3.8 \qquad t_o = (3.8)\ (1.67) = \underline{6.35 \times 10^{-3} \text{ sec}}.$$

Using a similar proof as that shown for impulse $t_{o2} = nt_{o1}$,

then t_o for 300 lb = nt_o for 4.7 lb,

$t_o = 4 \times 6.35 = 25.4$-msec expected positive pulse duration for 300 lb of 9404 at full scale.

The above calculations give values that we could expect from the detonation of 300 lb of 9404 high explosive at Building 816.

The use of TNT curves to project results for explosives other than TNT may result in some inaccuracies. It is the feeling of the authors that these discrepancies will be rather small and compatible with the accuracy of the test results.

Table 2. Test parameters.

Shot	W_t	W_p	$W_t^{1/3}$	Loc.	P_{so}	I_s	t_o	Z_p	R_p	$I_{s/w}^{1/3}$	Z_I	R_I	$t_{o/w}^{1/3}$	Z_t	R_t
101	2	128	1.26	A	2.1	7.0	6.1	26	32.76	5.56	18.0	22.7	4.84	70	88.2
109	2	128	1.26	B	2.3	7.1	5.2	24	30.24	5.63	18.0	22.7	4.13	38	47.9
128	4	256	1.59	A	3.5	11.1	6.0	18.0	28.62	6.98	14.5	23.0	3.77	28	44.5
126	4	256	1.59	B	3.3	11.0	5.7	18.5	29.42	6.92	14.5	23.0	3.58	24	38.2
Projected	4.69	300	1.67		3.5	12.36	6.35	18.1	30.26	7.4	13.69	22.85	3.8	27.7	46.2

Using Ref. 6, pp. 4-8.

W_t = test charge (lb),

W_p = prototype charge (lb),

t_o = positive pulse duration (msec),

I_s = scaled unit positive incident impulse,

P_{so} = peak positive incident pressure,

R_p = radial distance from charge, ft, based on test pressure,

Z_p = scaled ground distance, ft/lb$^{1/3}$, based on test pressure,

R_I = radial distance from charge (ft), based on test impulse,

Z_I = scaled ground distance, ft/lb$^{1/3}$, based on test impulse,

Z_t = scaled ground distance, ft/lb$^{1/3}$, based on test time,

R_t = radial distance from charge (ft), based on test time.

COMPUTER INPUT

Material

This analysis is based on the largest asbestos cement wall panel at the north end of Building 816. Panel size is 6 ft 7 in. high × 47 in. wide × 1-1/8 in. thick Transitop.*

Two-Way Slab Theory

Using ACI building code[4] method 3 for determining proportions of load carried in the horizontal and vertical directions, calculations are as follows:

$$m = \frac{A}{B},$$

where

B = long slab dimension and

A = narrow dimension.

*Transitop is the Johns Manville brand name for an asbestos cement product with 1/8-in.-thick asbestos cement "skin" and a dense wood filler.

Case (1) is a slab simply supported on all sides.

From Table 3, Method 3 — Coefficient for live load positive moments in slabs,

$$m = \frac{47}{79} \approx 0.60,$$

$$c_A = \text{moment coefficient in A direction} = 0.081,$$

$$c_B = \text{moment coefficient in B direction} = 0.010.$$

Load carried by a unit beam in the narrow or A direction is approximately

$$\frac{0.081}{0.081 + 0.010} = 90\%.$$

Data

1. Initial force on the unit beam
   = 3.5 psi × 1 in. width × 47 in. length
   = 164.5 pounds.
2. Weight of structure at 4.2 lb/ft^2 = $\frac{1 \times 47}{144} \times 4.2 =$ 1.37 lb.
3. Spring constant.

   A calculation was performed using ASTM specifications C-220-67 and C-459-67.

It was calculated from specifications that 5/8 in. asbestos cement panels give a modulus of elasticity of approximately 1.9×10^6 psi. For our 1-1/8 in. panel using less asbestos cement material percentagewise, a modulus of elasticity of 1.8×10^6 psi will be assumed.

Using a 47-in. span and a unit beam 1 in. wide and 1-1/8 in. thick, and a slab factor of 10%:

$$E = 1.8 \times 10^6 \text{ psi},$$

$$I = \frac{bh^3}{12} = 0.119 \text{ in.}^4,$$

$$L = 47 \text{ in.},$$

Δmax at center = 1 in.

Solve for W:

$$\Delta\text{max} = \frac{5\ WL^4}{384\ EI} \qquad W = 3.38 \text{ lb/in.}$$

(1.1) wL = K (spring constant) = 175 lb

4. Positive pulse duration from calculations
   = 25.4 milliseconds.

5. Total time — use 0.5 sec — 1/2 sec.

6. Time increment — use 0.001 sec — 1 msec.

Predicted Static Breaking Pressure and Deflection

Ultimate load from Johns Manville specifications for a 6-ft span of 1-1/8 in. Transitop is 80 lb/ft^2:

$$m = \frac{wL^2}{8} = f_u S_x ,$$

where

m = moment in pound-inches,

f_u = ultimate stress (using ultimate load),

S_x = section modulus in $in.^3$,

L = span length,

W = uniform distributed load,

$$f_u = \frac{\frac{80}{144} (6 \times 12)^2}{8\ (0.212)} = 1700\ \text{p[illegible]}$$

For a 47-in. span solve for W_u, [illegible]

W_u = ultimate unif[illegible] load:

$$m = f_u S_x = [illegible]^2 .$$

$$W_u = \frac{8 f_u S}{[illegible]} \quad [illegible]\ \underline{lb/in.}$$

Since we are using [illegible] 1 in. w[illegible], the ultimate static pressure also equals 1.3 psi.

Now, solving for [illegible] deflection Δ_u,

$$\Delta_u = \frac{[illegible]}{384\ EI}$$

$$\Delta_u = \underline{0.3[illegible]\ in.}$$

As a check, Johns Manville predicts 0.072 in. deflection for a 4-ft span with 20 lb/ft^2 live load.

$$\frac{80\ \text{lb/ft}^2}{20\ \text{lb/ft}^2} \times 0.072 \approx \underline{0.29\ \text{in.}} < 0.385\ \text{in.}$$

This apparent discrepancy could be explained by the elasto-plastic and plastic condition during which the load is not linearly related to deflection.

COMPUTER-PREDICTED DEFLECTIONS

Table 3 is a listing of computer and calculation results based on the LLL-developed program.

Table 3. Computer and calculation results.

Material	1-1/8-in. Transite	2-in. Transite	1-1/8-in. Transite
Span (in.)	47	47	22
Max deflection (in.)			
Allow	0.385	0.217	0.085
Computer	1.57	0.32	0.131
Time at max deflection (sec)	0.131	0.007	0.004
Period (sec)	0.028	0.014	0.0077
Max stress (psi) bending			
ultimate allowable	1700	1700	1700
computer	6940	2270	2640

It can be seen from the above deflections that the existing 1-1/8 in. material with 47 in. span would fail as would 2 in. material with 47 in. span and 1-1/8 in. material with 22 in. span. These results prompted a calculation of 2 in. material with a 22 in. clear span which proved to be the final design.

WALL DESIGN

A good correlation can be seen between the LLL computer program and curves developed by the U.S. Army Corps of Engineers for maximum response of one-degree elastic systems (undamped) subject to triangular load pulse with zero time rise.[5] The following

calculations show a check on one of the computer solutions as well as a final wall design. It is noted that when a triangular or rectangular load pulse is closely approximated, use of the rigorous analysis curves[4] is the best method of design. For load pulses other than triangular or rectangular, a computer program which will allow solution of a discontinuous function which describes a load pulse would be of great value.

2-in. Transitop – 47-in. span, 1-in.-wide Unit Beam

$$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{1.86}{\frac{(32)\ (12)}{976}}} = 0.0141 \text{ sec},$$

$$t_d = 0.0254 \text{ sec},$$

$$\frac{t_d}{T} = 1.80,$$

Dynamic load factor, $(DLF)_{max}$, from Ref. 6, p. 46, = 1.75

$$\text{Maximum stress} = 1.75\ \frac{(WL^2/8)}{S_x}\ (0.9)$$

Where:

S_x = Section modulus (in.^{3}) = 0.667,

W = Initial load (lb/in.) = 3.5,

L = Span (in.) = 47.

The (0.9) reduction is due to the slab factor, shown earlier to be approximately 10%.

$$\text{Maximum stress} = (1.75)\ \frac{966}{0.667}\ (0.9) = 2280 \text{ psi},$$

2260 psi ≈ 2270 psi (from computer).

The time of maximum response is also from Ref. 6, p. 46:

$$\frac{t_m}{T} = 0.47,$$

$$t_m = (0.47)\ (0.014) = 0.0066 \text{ sec},$$

0.0066 sec ≈ 0.007 (from computer).

Final Wall Design

Following are calculations for the materials used in the final wall:

2-in. Transite — 22-in. span, 1-in.-wide unit beam pressure — 3.5 psi

t_d = 0.0254 sec,

$$T = 2\pi \sqrt{\frac{\frac{\frac{22}{144}(5.7)}{(32)\quad(12)}}{9500}} = 0.0308 \text{ sec} .$$

Weight of 2-in. Transite = 5.7 lb/ft^2,

K (spring constant) = 9500 lb/in.,

$\frac{t_d}{T} = \frac{0.0254}{0.0308}$ = 0.825 (from Ref. 4, p. 46) D.L.F. = 1.45,

$\frac{t_m}{T}$ = 0.44,

t_m = (0.44) (0.0308) = (0.0136 sec

Maximum stress = (1.45) (0.9) $\frac{(WL^2/8)}{S_x} \simeq$ 414 psi

where

S_x = 0.667 in.^{3},

W = 3.5 lb/in.,

L = 22 in.

414 psi < 1700 psi ultimate allow

Safety Factor $\simeq \frac{1700}{414}$ = 4.1.

4 in. × 3 in. × 1/4 in. wall structural tubing — 2 ft - 0 in. spacing, 6 ft - 6 in. span — weak direction

Properties of tube:

$I_y = 4.10$ in.^{4}, $S_y = 2.74$ in.^{3},

$W = 10.5$ lb/ft solve

$E = 29 \times 10^6$ psi

$L = 78$ in.

$\frac{L}{r} \approx 28.5.$

For spring constant k:

$$\Delta_{max} = 1 \text{ in.} = \frac{5WL^4}{384EI},$$

$W = 247$ lb/lin. in.

$K = wL = (247)\ (78) = 19{,}270$ lb/in.

$$T = 2\pi \sqrt{\frac{\frac{(10.5)}{(32)}\ \frac{(6.5)}{(12)}}{19{,}270}} = \underline{0.0191 \text{ sec}}$$

$$\frac{t_d}{T} = \frac{0.0254}{0.0191} = 1.32$$

D.L.F. $\approx$ 1.65.

$W = 3.5$ psi $\times$ 22 = 77 lb/lin. in., $L = 78$ in.

$$\text{Maximum stress} = 1.65\ \frac{(WL^2/8)}{S_Y} = \frac{(1.65)(77)(78)^2}{(8)\ (2.74)} = 35{,}260 \text{ psi}$$

35,260 psi < 60,000 psi ultimate allowable.

$$\text{Safety factor} = \frac{60{,}000}{35{,}260} = 1.7.$$

A-307 Bolts and Spacing

End reaction of tubing = 3.5 × 12 in. $\frac{78}{2}$ ≈ 1640 lb/ft. 1/2-in. Wej-it bolts with min 1-1/2-in. embedment in 3700-psi concrete will provide 6600 lb shear.

U: /2-in. × 5-in. Wej-it at 2 ft (max) center-to-center spacing.

Safety factor = $\frac{6600}{3280} \simeq 2.0$.

Calculations are shown for flexure only. It is assumed that components are all right for shear because of their relative flexibility.

MATERIAL TESTING

Test Structure

Figure 5 is a design for a steel test structure that approximates conditions which would exist after the proposed Bldg. 816 end wall modifications. The three combinations tested were:

1. 2-in. Transite with 24-in. C.-C. supports.
2. 1-1/8 in. Transite with 24-in. C.-C. supports.
3. 2-in. Transite with 48-in. C.-C supports.

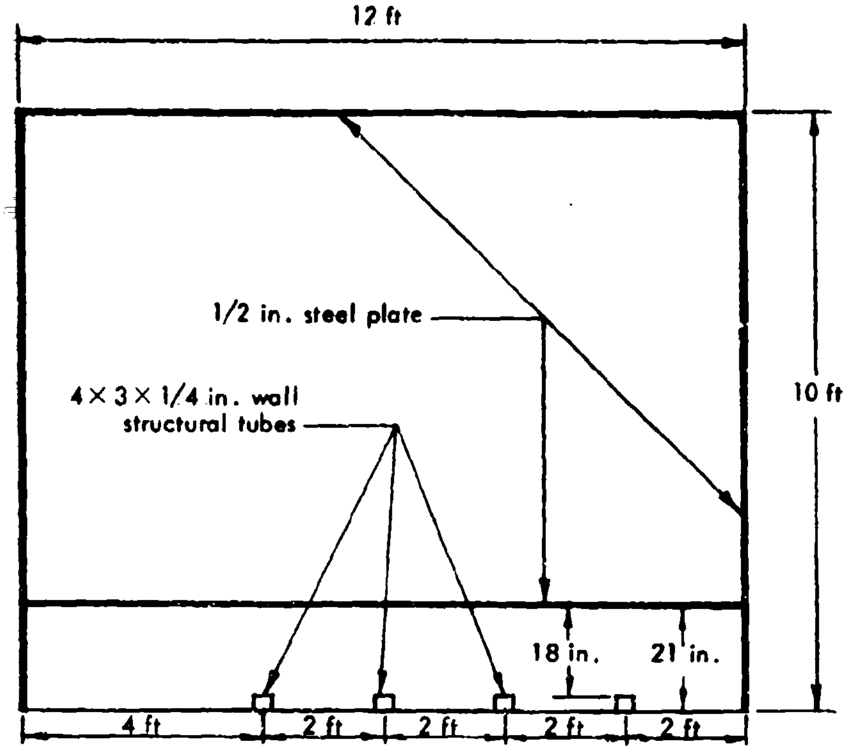
Shot Geometry

Several shots were fired and pressures were recorded in an attempt to match the predicted results from a 300-lb accidental detonation at Bldg. 816. It was noticed that a pressure wave was degraded when it traveled through the pressure wave of another shot. The geometry of the shot that was finally selected is shown in Fig. 6.

Test Results

Results from the material test shot compared with the projected 300-lb results are as follows:

	Test Shot	Projected 300-lb detonation
1. Maximum positive peak overpressure (psi), 1st peak:	4.9	3.5
Maximum positive peak overpressure (psi), 2nd peak:	4.9	3.3
2. Positive pulse duration (milliseconds):	17	25.4
3. Positive impulse (psi-msec):	32	49
4. Negative impulse (psi-msec):	40	23



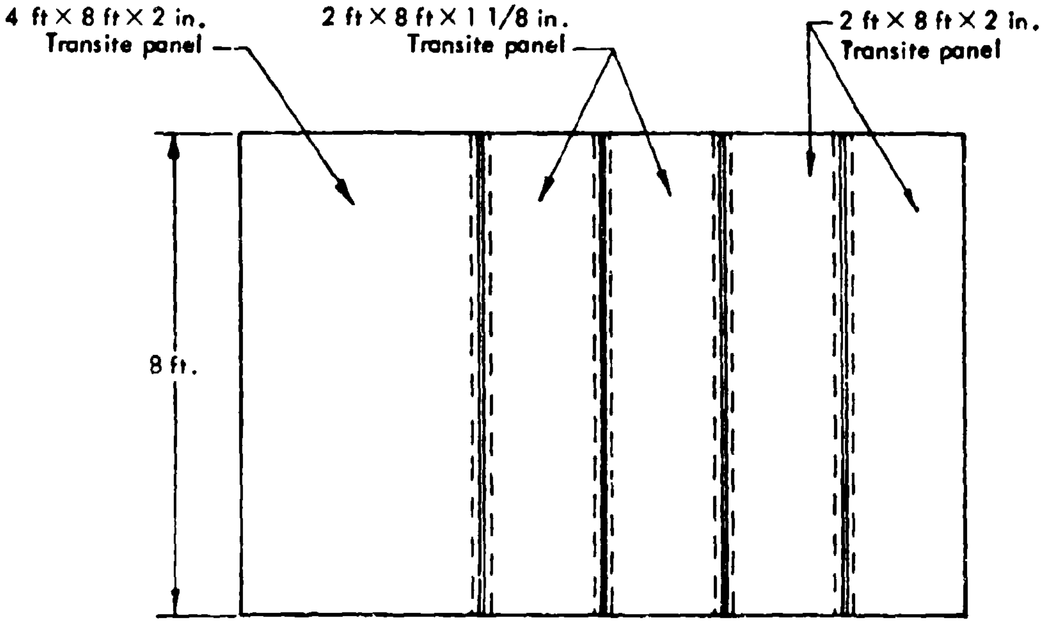


Fig. 5. Design for steel test structure. (a) Plan view; (b) front elevation.

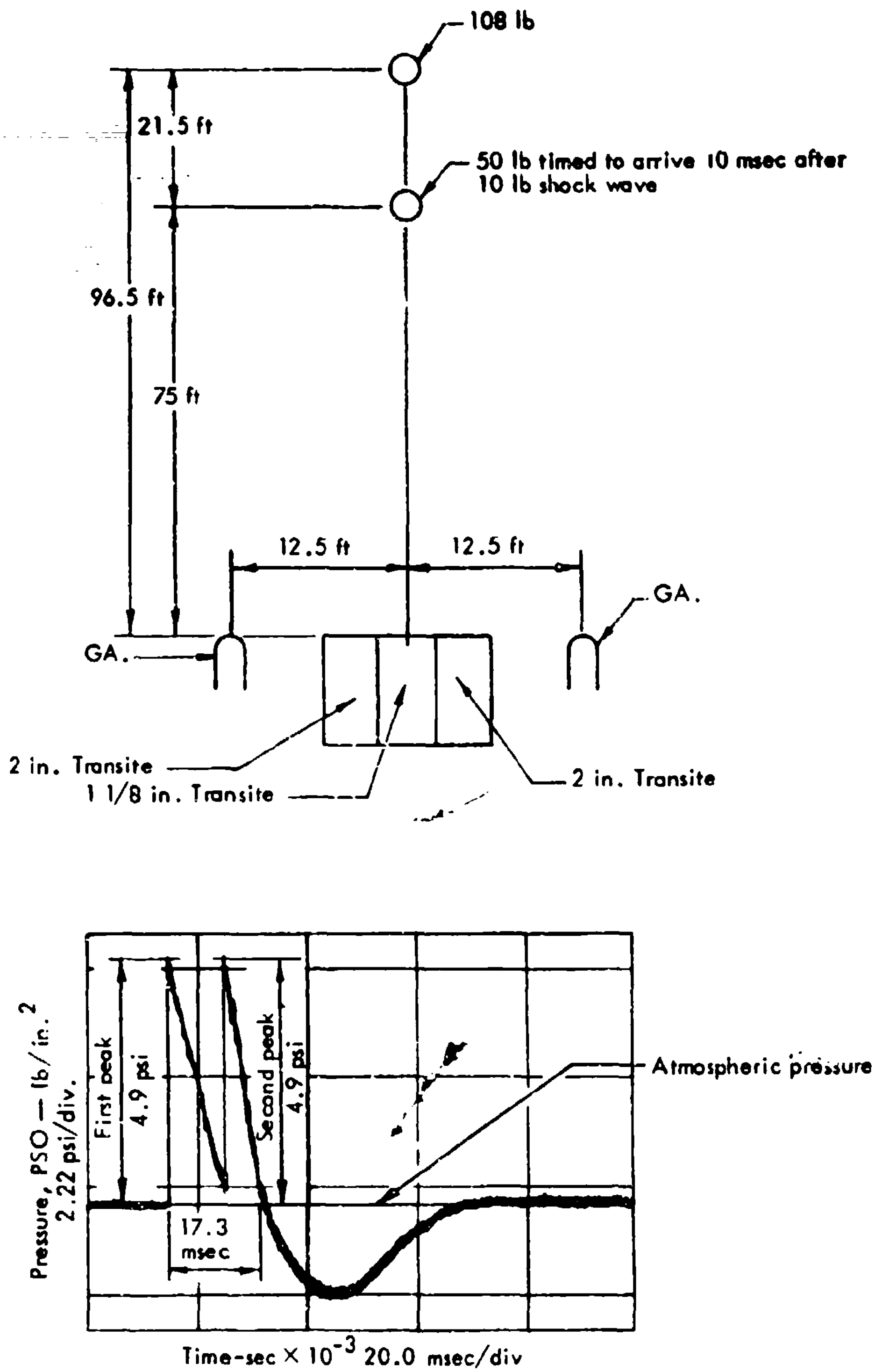


Fig. 6. (a) Test shot layout; (b) test shot pressure-time history.

The test shot produced positive peak overpressures of greater magnitude than the required 3.5 psi, but both positive pulse duration and positive impulse were less. A comparison of the negative impulse shows 40 psi-msec for the test shot as compared to 23 psi-msec for the projected 300-lb detonation. The 40 psi-msec negative impulse of the test shot compared favorably with the 49 psi-msec positive impulse projected for a 300-lb detonation, and was the apparent cause of failure in two of the test panels since in earlier test runs and even in the final test, failure occurred because of the negative impulse.

It is noted that negative impulse failure is fairly common when the pulse time is lengthened by multiple shock waves. In this case, the shock waves were lengthened by a planned delay. In many other structural failures this low-pressure, long-time duration impulse failure is caused by shot-structure geometry, with intervening structures providing the various arrival times. This phenomenon was the reason for the double-peaked results of the scale-model test. A redesign of the mounting bracket minimized local failure at the bolt clips due to a lack of support in the negative pressure or out of structure direction.

The 1-1/8-in. panel with 24-in. C.-C supports and the 2-in. panel with 48-in. C.-C supports both failed at predicted pressures created by the test shot. The final design panel withstood the shot with no failure, which agreed with design calculations.

Figures 7 through 11 are photographs of the scale model and test panels before, during and after testing.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The wall at Building 816 control room will experience the following approximate phenomena for a 300-lb detonation:

   Overpressure — 3.5 lb/in.^{2},

   Impulse — 49 psi-msec,

   Time of positive pulse duration — 0.025 sec.
2. Field testing of full-size test sections of wall proves the final wall design to be adequate.
3. The design method used should be valid for future design of blast-loaded structures. This applies to elastic design only.

Recommendations

1. Modify the north wall of Building 816 control room.

   Modifications to the existing wall will consist of:

   - Use 2-in. Transitop panels with a maximum clear span of 22 in.
   - 4-in. × 3-in. × 1/4-in. structural steel tubing as the intermediate support to reduce the clear span.

Fig. 7. Scale model with HE charge in center. Gauges are mounted inside open end of structure in sand bags.

Fig. 8. Early panel test. Negative impulse failure. Edge supports are inadequate. Failure mode is explained by lack of proper negative support.

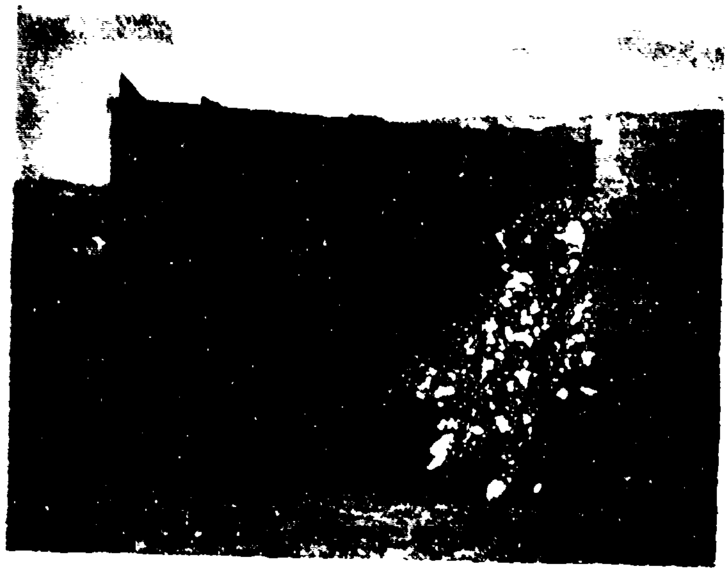


Fig. 9. Properly supported test panels before final panel testing. No bottom supports on any panels. Panels and supports left to right are: (1) 2-in. Transite, 48-in. C.-C supports, (2) 1-1/8 in. Transite, 24-in. C.-C supports, and (3) 2-in. Transite, 24-in. C.-C supports. (This is the test condition that approximates the final wall design.)

Fig. 10. Final panel test after shot. Failure mode is as expected. Diagonal cracks to the bottom corners are absent because bottom edge was unsupported. Final wall design on right shows no sign of failure.

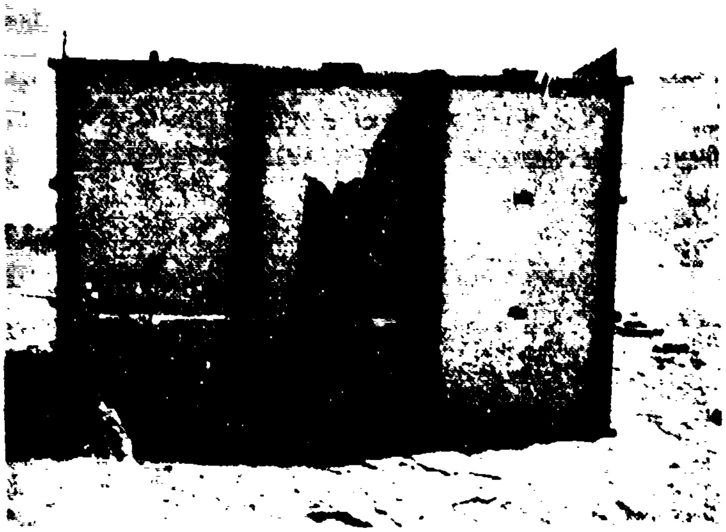


Fig. 11. 50 lb of HE at 50 ft, fired after final test shot. Panels were already weakened.

- 1/2-in. × 5-in. anchor bolts with a 2-ft - 0 in. maximum spacing for anchoring wall frame to reinforced concrete opening.

2. A computer program that could handle data from various shaped pressure-time history curves and elasto-plastic structure response would be useful.

ACKNOWLEDGMENTS

Support in structural theory was provided by Steve Szybalski and John King of Plant Engineering. Steve Szybalski and Hews McCann were responsible for the computer program. John King provided editorial assistance.

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FAILURE STRENGTHS OF WALL PANELS UNDER EXPLOSIVE LOADING

Chuck Wilton, B. L. Gabrielson, and Kenneth Kaplan
URS Research Company
San Mateo, Calif.

CONTENTS

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INTRODUCTION AND SUMMARY

One of the major problems facing a designer when attempting to design structures to resist explosive forces is the paucity of actual test data. Most structural designs and design problems are well tested in the laboratory. However, the very nature of the explosion problem tends to limit the testing effort, and especially any effort to carry out full-scale tests. Such tests have been conducted, however, by URS Research Company, and this paper is designed to bring to the design community some of the data URS has gathered on full-scale walls subjected to blast loading.

For about five years, URS Research has been involved in a rather extensive research program (sponsored by the Defense Civil Preparedness Agency) to derive information on the loading, structural response, and debris characteristics of structural wall panels. The primary purpose of the program is to provide information to improve estimates of building damage and casualties from nuclear and natural disasters.

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Full-scale (8-1/2' x 12') walls with and without openings (doors and windows) have been subjected to a blast environment in a large shock tunnel. Some of the walls, used for calibration purposes, were specifically designed not to fail under blast loadings. The others, the test walls, were built using standard practices and materials. Test walls were made of brick, concrete block, tile, timber studs and sheetrock, and reinforced concrete, with emphasis to date on the brittle materials. The walls were mounted as beams (supported on two sides) and plates (supported on all four sides), and were also preloaded* and arched.**

Results of the program to date are summarized in the three-part Failure Strength Matrix of Figure 17, reproduced here for convenience.

* A preloaded wall is one in which vertical forces, simulating the weight of walls above the wall of interest, are applied prior to shock wave loading.

** Arching of a wall panel loaded by a shock wave normal to its face takes place when the panel supports permit essentially no motion in the direction of the plane of the panel. This can occur when a wall is tightly supported in a rigid frame.

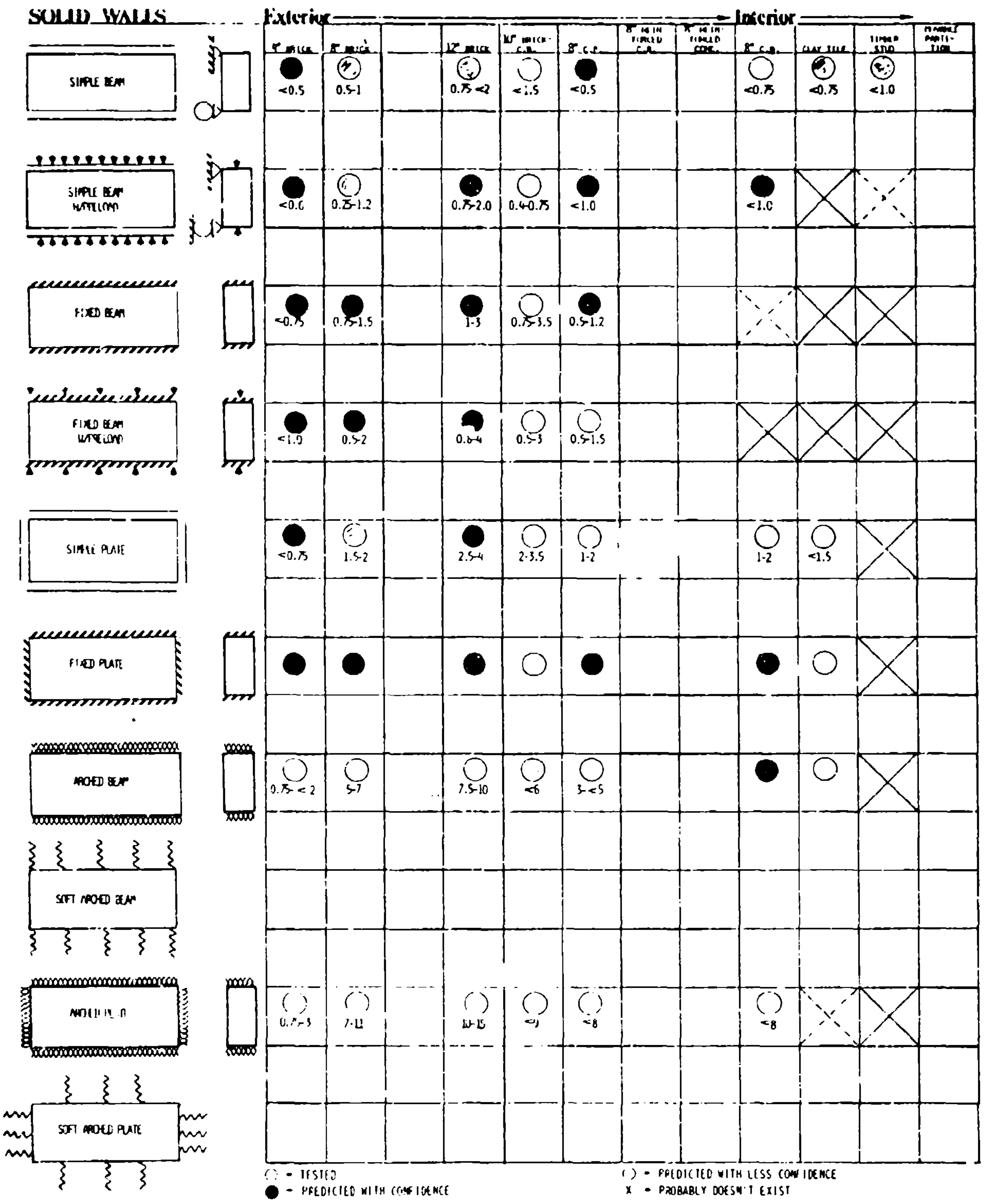


Fig. 17 Failure Strength Matrix - Solid Walls

WINDOWS — Exterior → Interior

WINDOWS	4" BRICK	8" BRICK		12" BRICK	10" BRICK C.B.	8" C.B.	7" REINFORCED C.B.	8" REINFORCED CONC.	7" C.B.	CLAY TILE	TIMBER STUD	MOVABLE PARTITION
SIMPLE BEAM	● <1.0	○ 0.75-1.75		● 1.5-4	○ <1.5	○ <0.75			X	X	X	
SIMPLE BEAM W/PRELOAD	● <1.0	○ 0.5-2.4		● 1-5	○ 1.5-4	○ 0.75-2			X	X	X	
FIXED BEAM	● <1.0	● 1.2-1.6		○ 1.5-4	○ <4	○ <3			X	X	X	
FIXED BEAM W/PRELOAD	○ <1.5	○ 1.3		○ 1.5-5	○ <5	○ <3			X	X	X	
ARCHED BEAM	○ 1-4	○ 6-9		○ 9-12	○	○			X	X	X	
PARTIAL (SOFT) ARCHED BEAM												
ARCHED PLATE									X	X	X	
PARTIAL (SOFT) ARCHED PLATE												

( ) = TESTED
● = PREDICTED WITH CONFIDENCE
( ) = PREDICTED WITH LESS CONFIDENCE
X = PROBABLY DOESN'T EXIST

FIG. 17 FAILURE STRENGTH MATRIX - WINDOWS

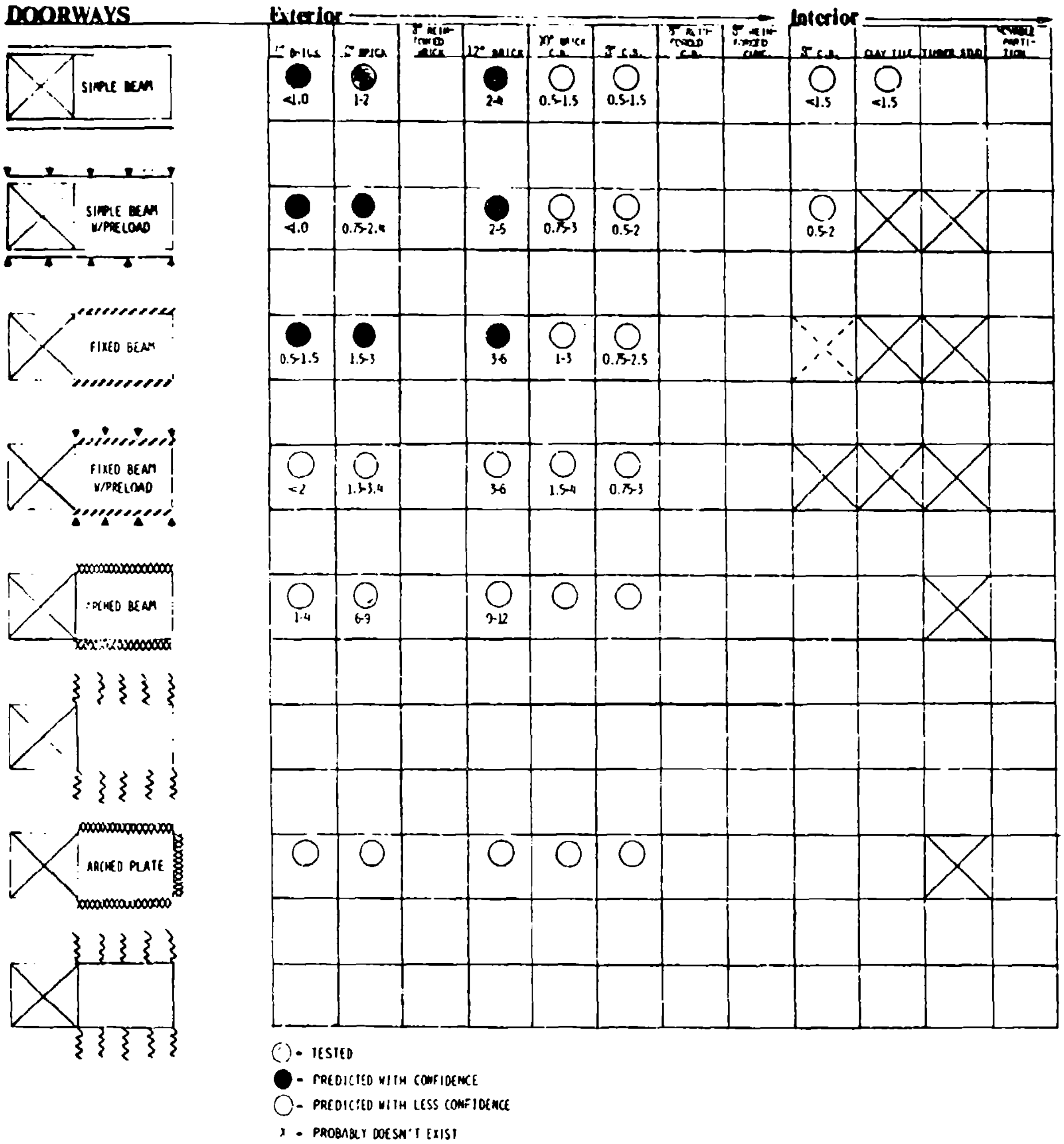


FIG. 17 FAILURE STRENGTH MATRIX - DOORWAYS

THE TEST FACILITY

The URS Shock Tunnel facility, used to conduct the test program, is part of a converted coastal defense complex. The shock tunnel, shown in Figs. 1 and 2 consists of a 163 ft long section of reinforced concrete.

The first 63 ft of the tunnel (the compression chamber) is 8 ft by 8.5 ft, lined with an 8 ft diameter by 3/8 in. thick steel cylindrical shell, closed at one end, and held in place with rigid foamed-in-place urethane foam (2 lb/ft^3 density).

The remaining 100 ft of tunnel is used as the expansion chamber and has an 8.5 by 12 ft cross section capable of accommodating "full scale" wall panels.

The tunnel is operated as a shock tube by means of the so-called volume detonation technique, with Primacord* as the explosive material. In this mode of operation, strands of Primacord are strung lengthwise throughout a section (up to 63 ft) of the compression chamber portion of the tunnel. Unlike conventional compressed-gas shock tubes, it is not necessary to separate the compression chamber from the expansion chamber with a frangible diaphragm. The detonation of the Primacord is sufficiently rapid (20,000 ft/second detonation velocity) that the compression chamber very quickly becomes filled with hot, high pressure gas. The expansion of this high pressure gas into the remaining part of the tunnel (the expansion chamber) generates the desired shock.

* Primacord, a trade name of the Ensign-Bickford Corporation, is also known as detonating fuse.

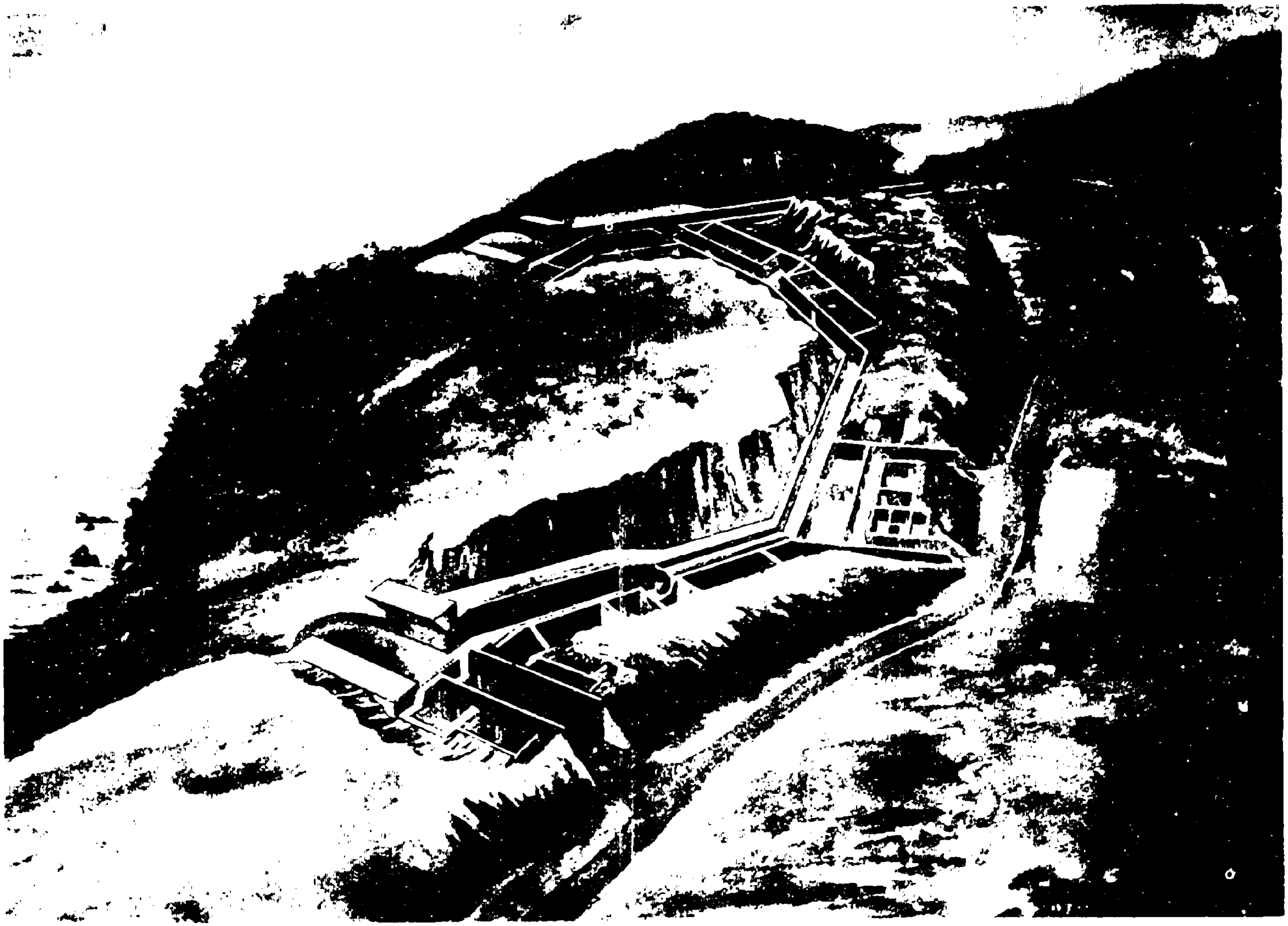


Fig. 1. Cutaway View of the URS Field Laboratory. The Shock Tunnel is in the foreground.

Nominal Gage Distances from Mouth of Compression Tube

STATION		ft
1	-	49
2	-	53
3	-	57
4	-	61
5	-	65
6	-	69
7	-	73
8	-	74
9	-	76
10	-	81
11	-	71.5

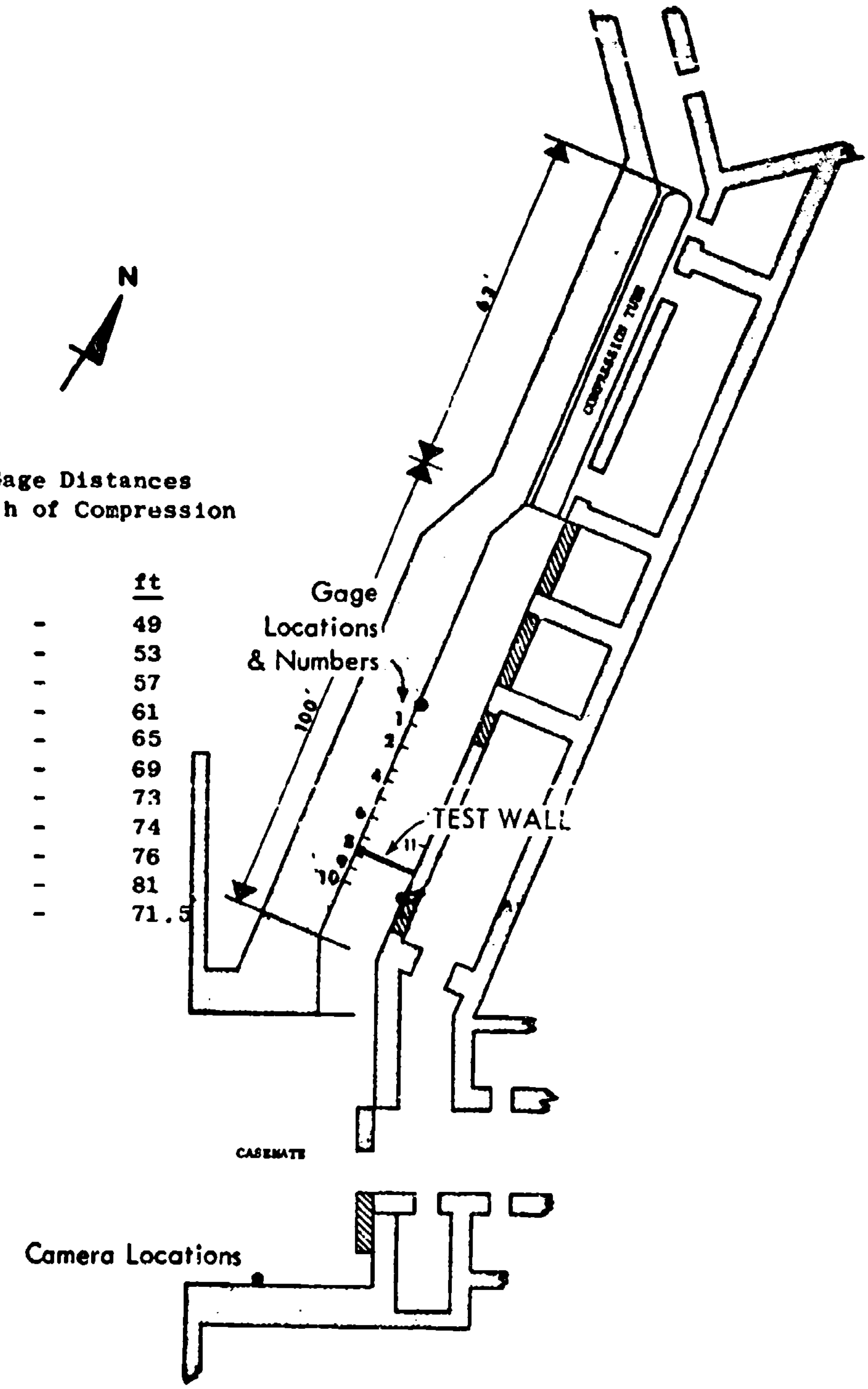


Fig. 2. Plan View of Shock Tunnel Facility.

The facility is capable of generating a shock wave with an overpressure (incident) of about 11 psi, which can result in a loading (reflected) overpressure on a wall completely blocking the tunnel of about 22 psi. The shock wave can be flat-topped for as long as 40 msec, with a total positive phase duration of about 100 msec. Pressure records from a shock wave with an incident overpressure of about 3.5 psi are shown in Fig. 3. The two top traces are from gauges in the tunnel side walls, upstream from a non-failing wall that completely blocked the tunnel, and are therefore stepped due to the arrival at the gauges first of the incident wave and then of the wave reflected from the wall. The lower traces are from gauges mounted in the upstream face of the non-failing wall, and therefore show only loading (reflected) pressure.

The system used to support walls to be tested is shown in Fig. 4 with an illustrative brick wall panel in a simple-plate configuration. The vertical plate girders are removable to provide a simple-beam support condition. The load cells provide data on load transmission to the support structure (tunnel walls) for both failing and non-failing wall panels.

Available instrumentation includes pressure, time-of-arrival, strain, displacement/velocity, and crack gauges, as well as the load cells mentioned earlier. Pressure gauge information is first digitized, then processed by a number of computer codes written for a time-sharing, XDS-940 computer available through Tymeshare, Inc. These codes provide: overpressure and impulse information for single gauges; net pressure and impulse information for paired gauges (gauges located on upstream and downstream faces of walls with openings); averages of these quantities for repeats of a single test condition; and also standard deviations, to provide a measure of gauge accuracy and test repeatability.

Velocity gauge records are also processed to provide plots of wall displacement vs time.

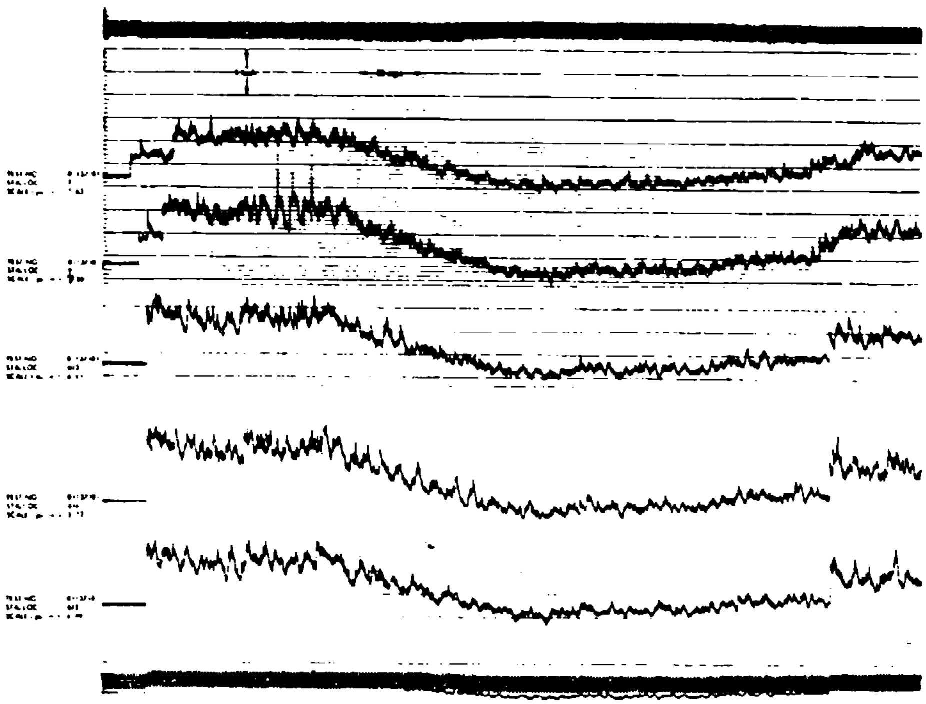


Fig. 3. Photocopies of Data From a Solid Wall Loading Study Test Using Three Strands of Primacord

THE TEST PROGRAM

The test program is divided into four basic parts

- Static tests
- Loading study tests (using non-failing walls instrumented with pressure gauges)
- Theoretical analyses
- Full-scale dynamic tests (using walls constructed with conventional materials and with conventional building practices)

These four parts are described in more detail in the remainder of this section. To avoid repetition, the static test description is restricted to walls of non-reinforced brick. Descriptions of the other parts of the program are restricted to walls with a doorway opening for illustrative purposes.

STATIC TEST PROGRAM

The static test program is conducted in conjunction with the shock tunnel dynamic tests to assure quality control in the construction of the test panels, and to obtain estimates of the strengths of the panels at the time they are tested in the tunnel.

The tests performed include

1. Brick and mortar beam tests for composite flexural behavior
2. Cylinder mortar for compressive strength
3. Cylinder mortar tests (splitting) for tensile strength
4. Brick flexure tests (flatwise for tensile strength

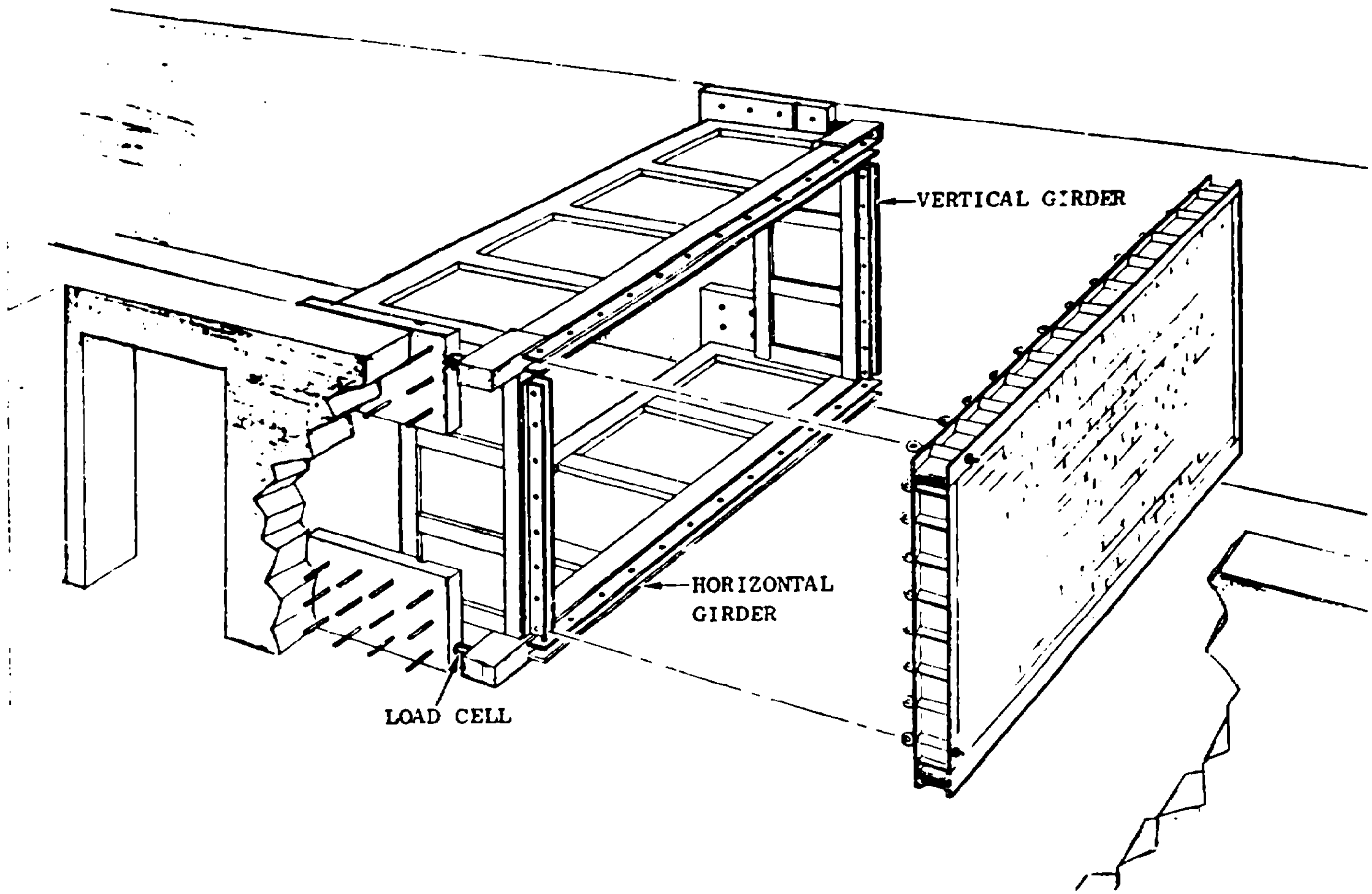


Fig. 4. Cutaway View of Shock Tunnel Showing Test Panel and Location of Horizontal and Vertical Plate Girders, Wall Blocks, and Load Cells

5. Brick flexure tests (edgewise) for tensile strength and to obtain a measure of directional properties

6. Brick tests for compressive strength

7. Brick and mortar tests for compressive strength and composite modulus

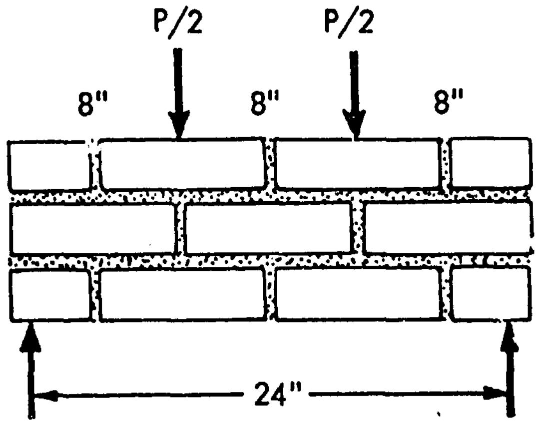
8. Brick and mortar couplets for tensile-bond capacity

9. Brick and mortar tests for shear-bond capacity.

All tests are performed per ASTM standards; either sulphur or plaster of paris is used as the capping material.

The brick and mortar beam tests (No. 1) are among the most revealing and meaningful of the static tests because of the manner of construction (like the walls) and the large size of the test specimens.

In these tests, brick beams approximately 26-½in. long, 9 in. high, and 8-½ in. wide are loaded at the one-third points as shown below.



Since these tests are partly quality control tests, at least one beam is made for each wall and these in turn are made in relatively small batches. The results for the first six batches of walls (22 walls) are plotted in Fig. 5. The plot clearly makes apparent the need of statistical procedure when discussing failure in brittle materials.

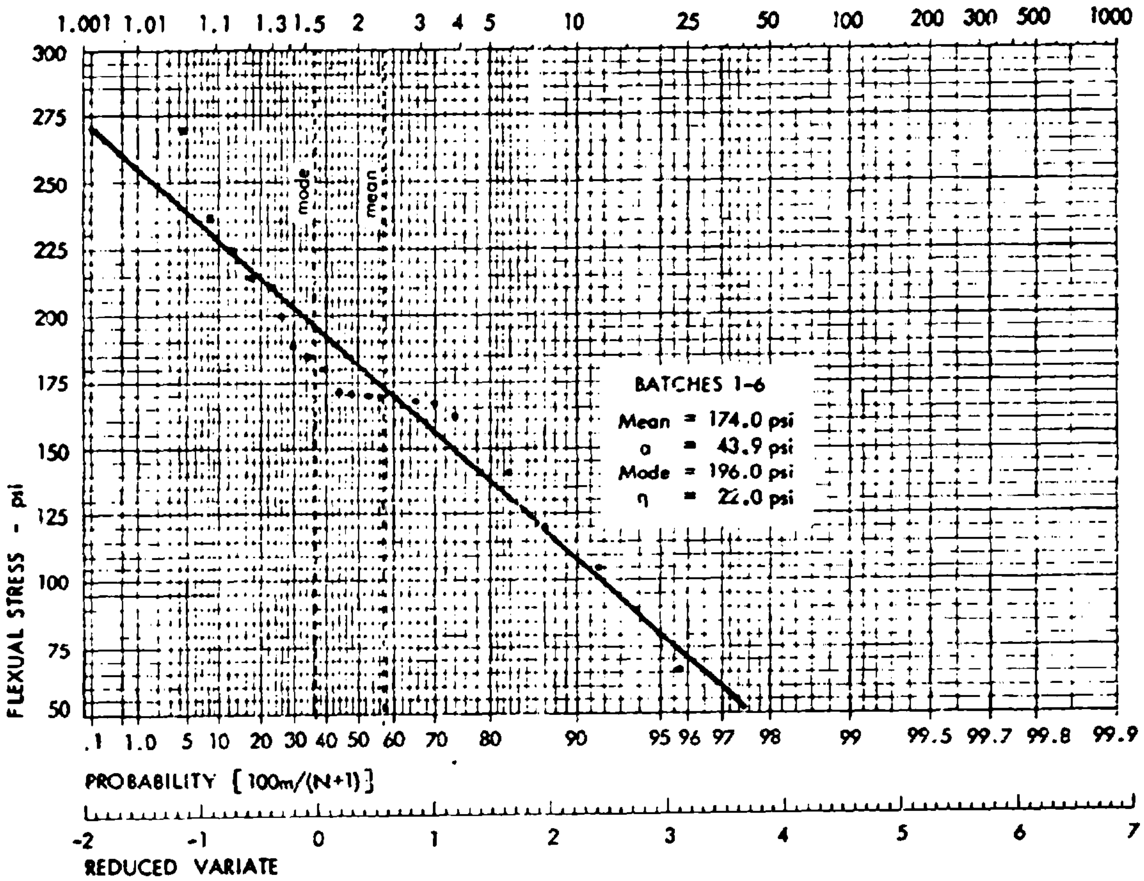
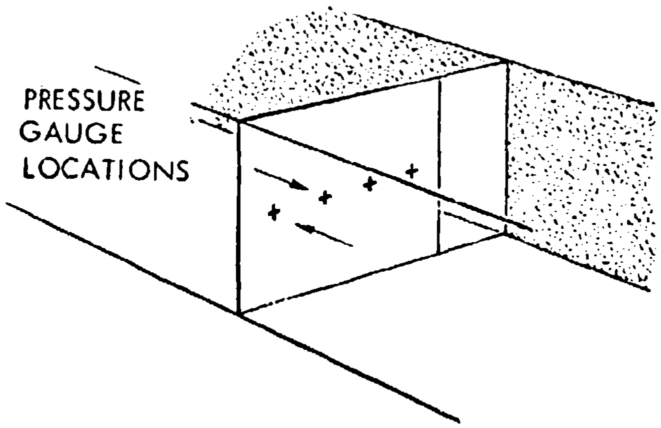


Fig. 5. Probability Plot of Flexural Stress (σ_t) From Brick Beam Tests

LOADING STUDY

This portion of the effort is concentrated on developing an accurate and complete description of the loading on structural elements. Obviously, shock wave overpressures with either the fully closed or fully open tunnel are quite simple - merely a step pulse for about 40, msec followed by a decaying exponential. These modes have been used extensively in instrumentation evaluation and development. The most interesting cases, however, are loadings on wall panels with openings, and on rooms. These more complex cases, coincidentally, are the cases for which the least is known. The loading information, of course, is vital to the structural analysis of the test wall and support system, as well as analyses of other walls with similar configurations.

The loading tests are carried out in the shock tunnel by installing instrumented modular non-failing walls. The modular nature of the wall permits a wide variety of configurations to be tested, i.e. walls with windows and/or doorways. Gauges are located in both upstream and downstream faces of the walls with openings. Typical locations of the gauge pairs for a wall with a doorway are shown below:



A series of tests is then conducted and net pressures (the differences between upstream and downstream pressures) at each location are established. Several replications at each incident pressure level are made and the results averaged. Figure 6 is a net pressure vs time plot for four gauge locations. Only 25 msec of data are shown as elastic failure occurs at an earlier time for brittle materials, and these data were used as input to computer elastic analyses.

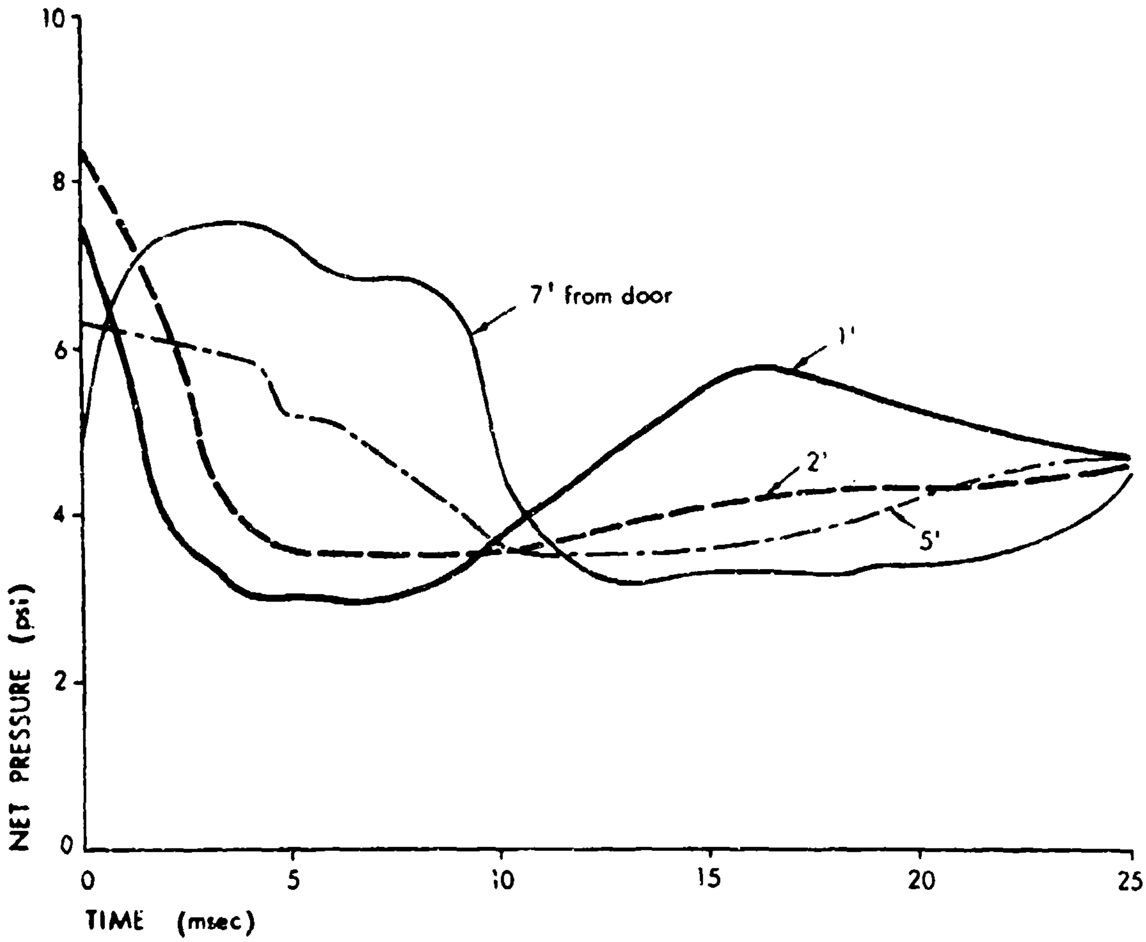


Fig. 6. Net Pressure vs Time

THEORETICAL (STRUCTURAL) ANALYSES

With the foregoing pressure (loading) data, structural analyses and response predictions can be attempted. Currently we are using a computer code (SAMIS)* developed by Philco-Ford Corporation, which is capable of dynamic analysis of finite element structural systems.

Figure 7 shows the basic element grid for our test system with line elements (2, 3, ., ., .) representing the support girder (simple beam support condition), and the triangular finite elements representing the wall. The shaded zone represents the doorway in our current example. Material properties are obtained from the static test program, and loads from the loading study. Figure 8 shows the simplified loads used in the computer analyses, based on those shown in Figure 6. The loads have been normalized so that peak reflected pressure is 1 psi. Deflections or stresses for any other pressure can be derived by simply multiplying by that pressure. These loads were applied over 2-ft vertical strips of the wall panel.

Figures 9 through 13 illustrate some typical output of the SAMIS code. Figures 9 and 12 show that, although the major motion is downstream, a secondary motion is induced by the load varying across the face. This causes the region furthest from the door to experience maximum displacement and stress (Figs. 9 and 13) before the region nearest the door. For example, these maxima occur at about 12 or 13 msec for node 10, but at about 18 msec for node 410.

* Structural Analysis and Matrix Interpretive System.

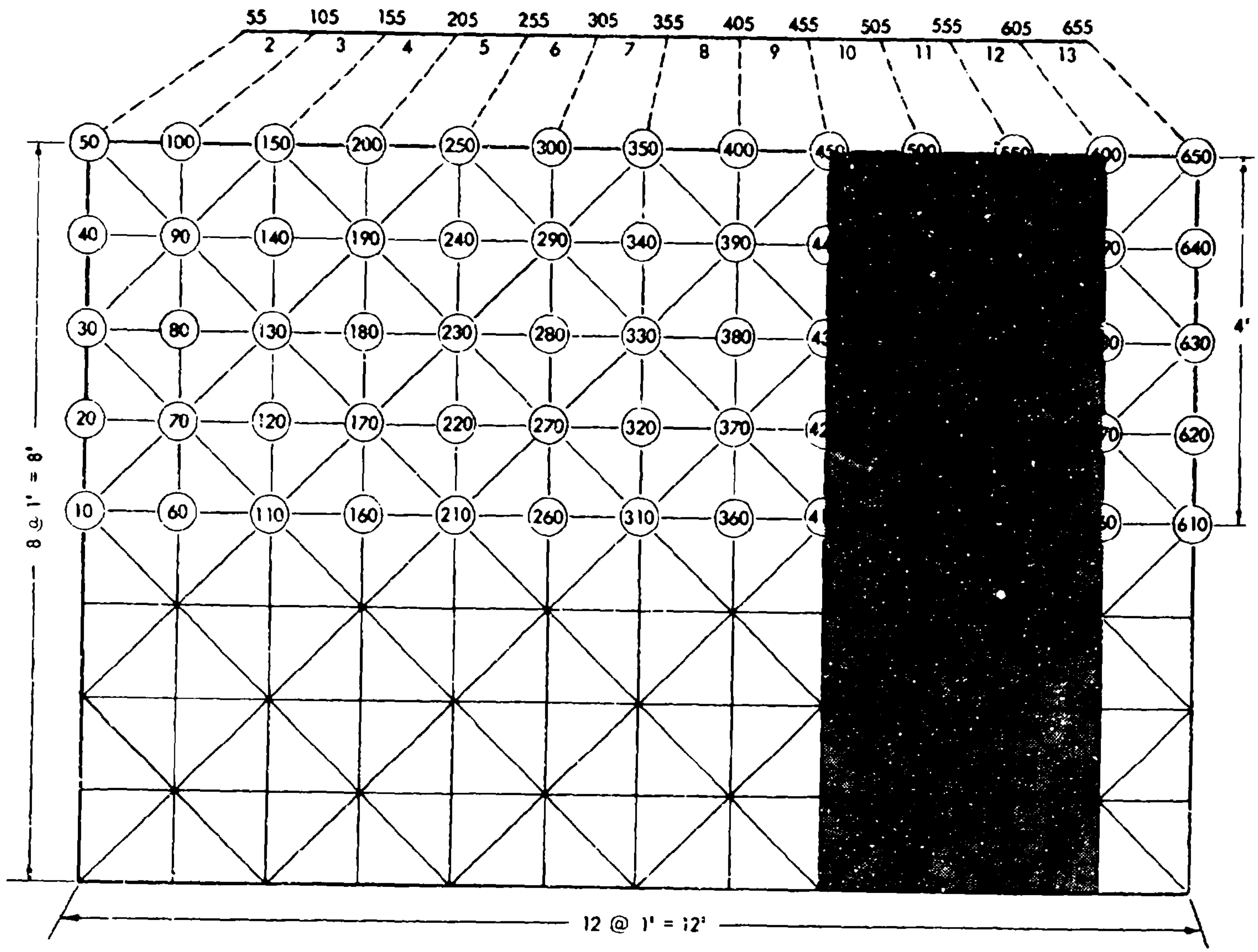


Fig. 7. Basic Grid and Line Elements for use in the SAMIS Computer Program

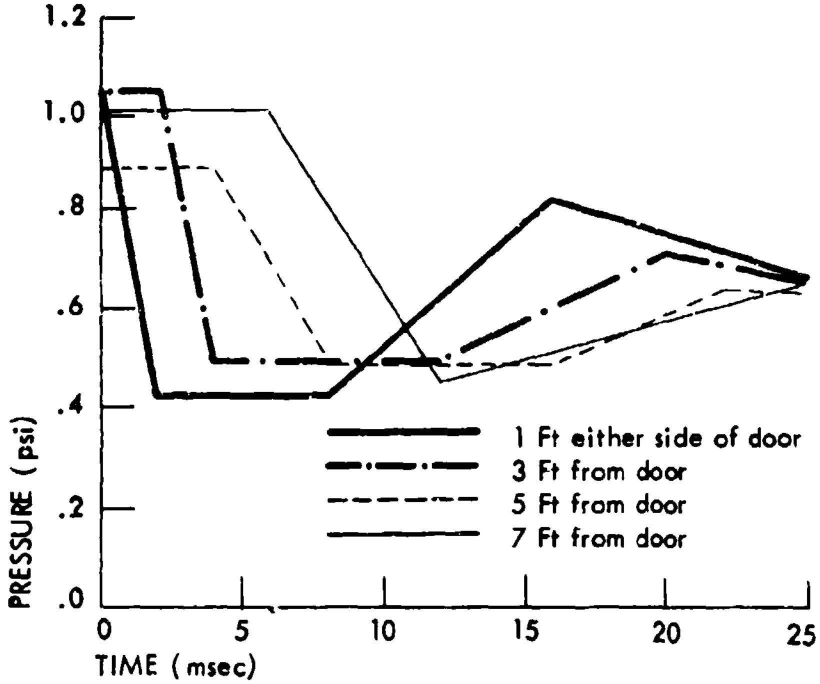


Fig. 8. Simplified Wall Loads Used in the SAMIS Computer Program

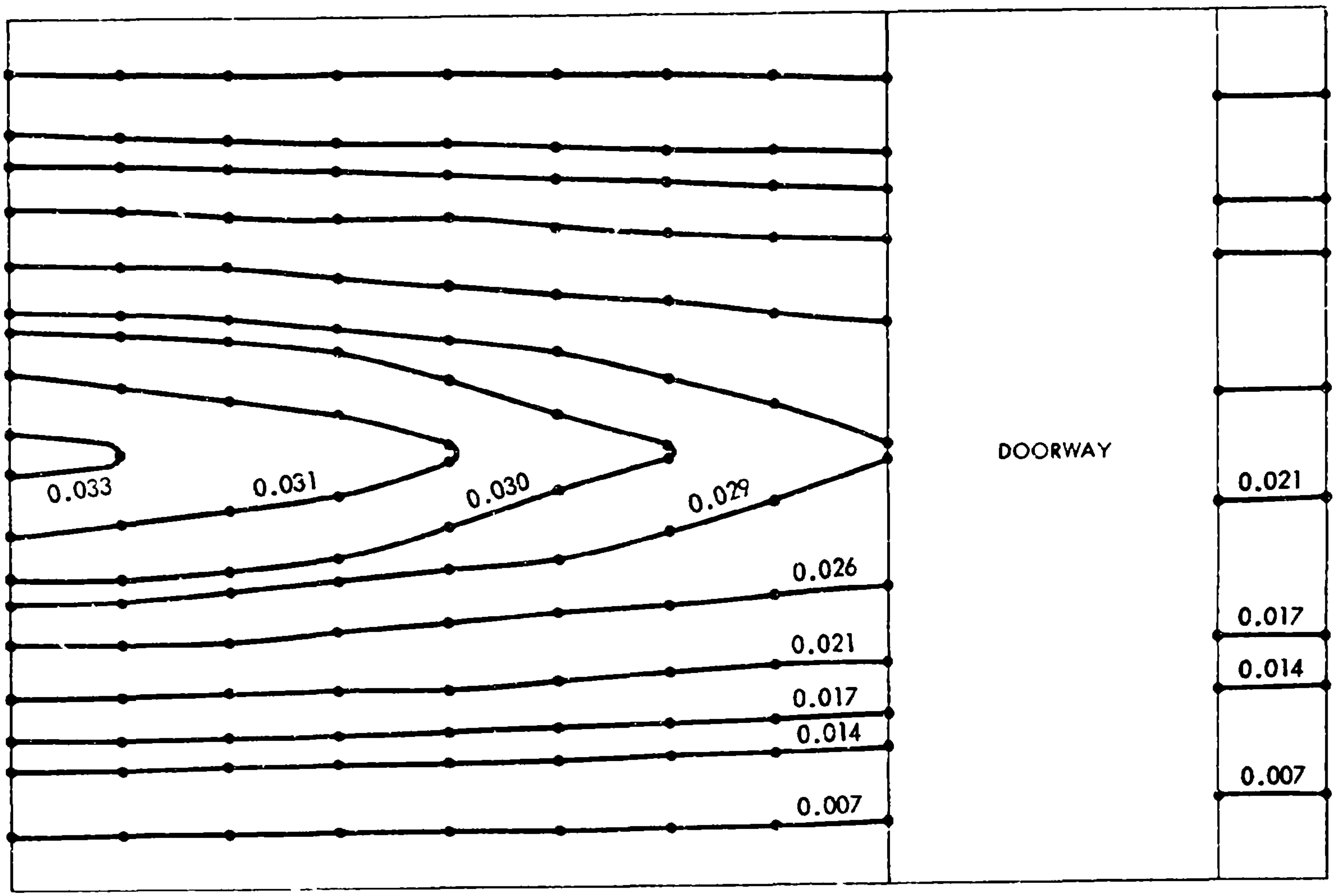


Fig. 9. Displacements at $t = 0.013$ sec for $p_f = 1.0$ psi

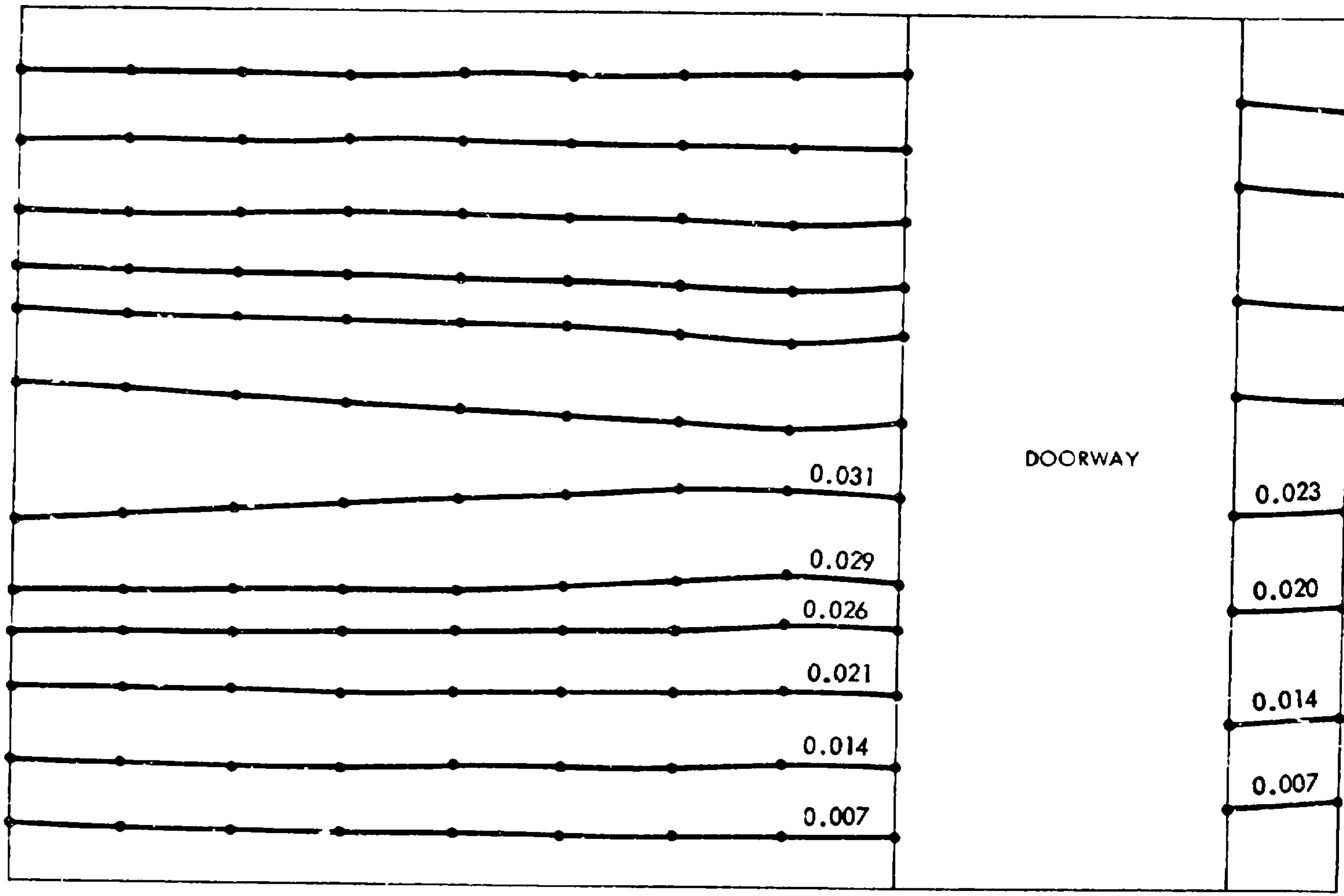


Fig. 10. Displacements at t = 0.014 sec for p_f = 1.0 psi

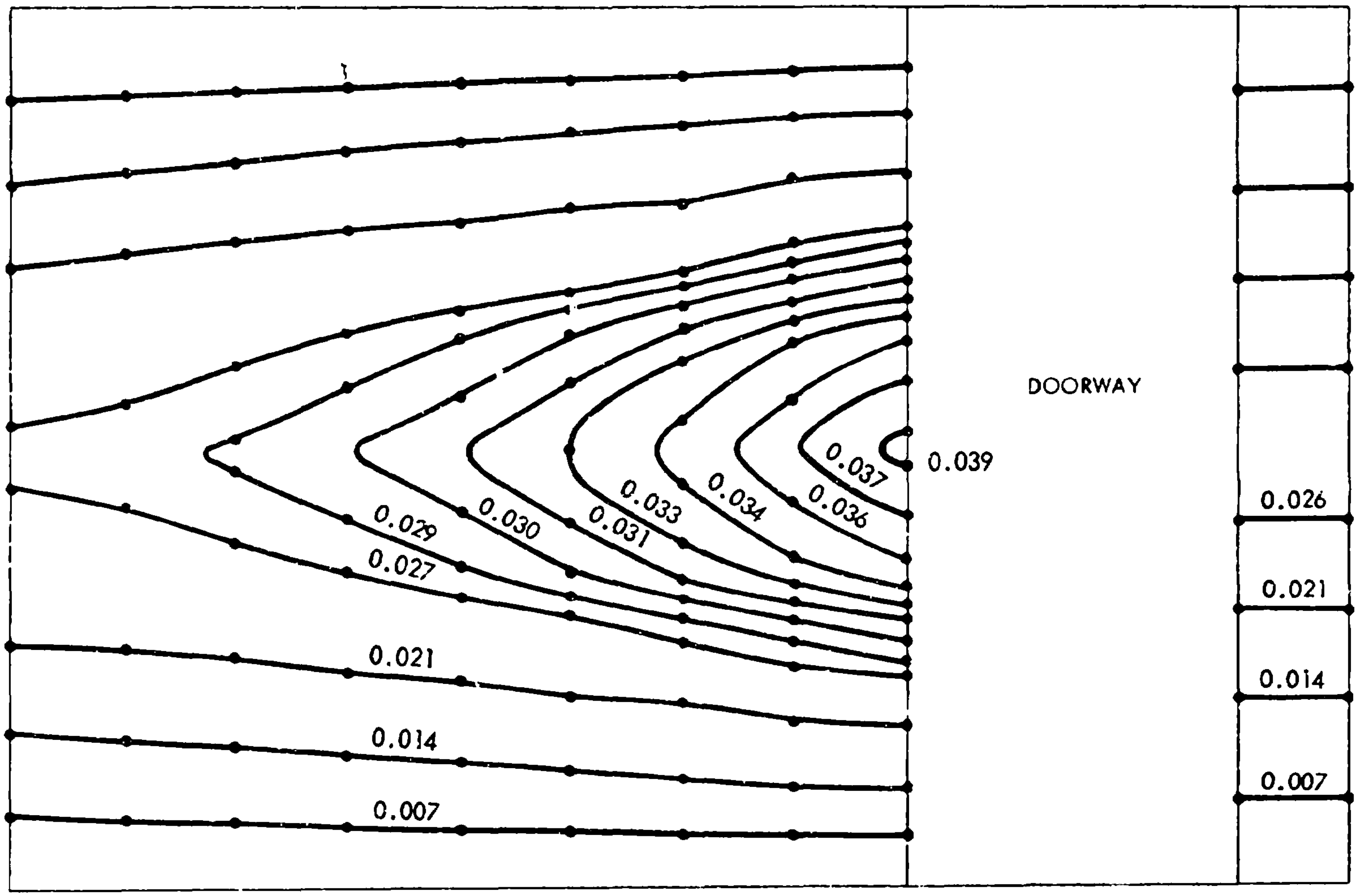


Fig. 11. Displacements at t = 0.017 sec for p_f = 1.0 psi

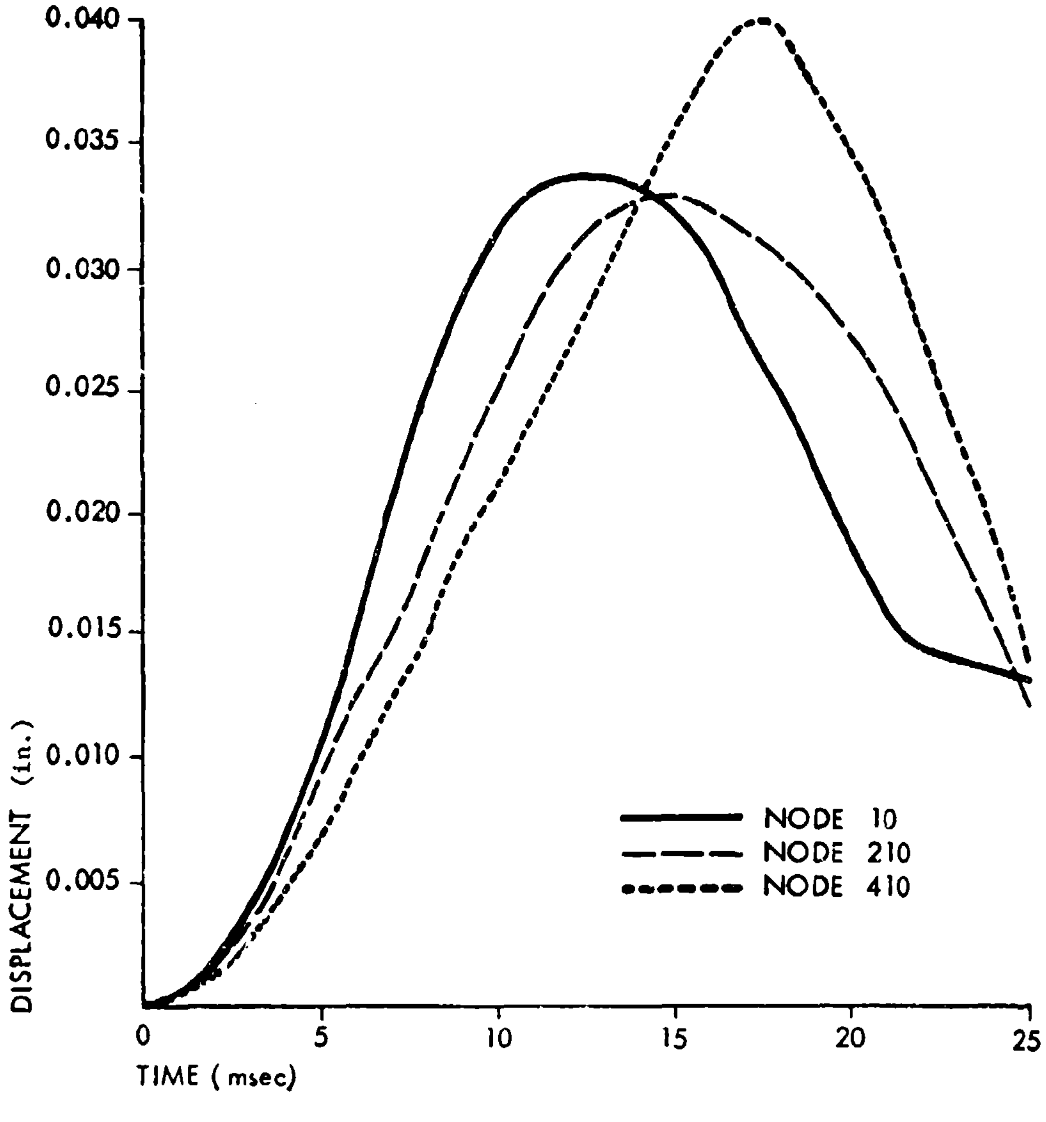


Fig. 12. Displacement vs Time of the Node Nearest the Tunnel Wall (Node 10), the Node Nearest the Doorway (Node 410), and the Node Halfway Between (Node 210) for $p_f = 1.0$ psi.

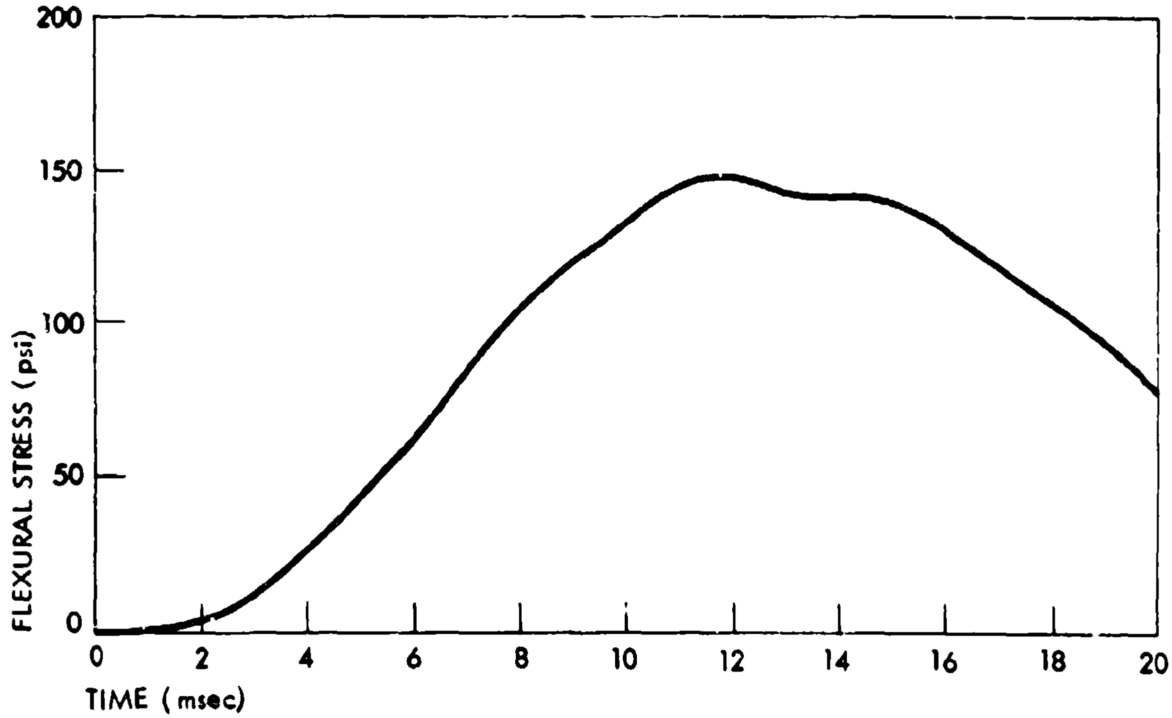


Fig. 13. Doorway Wall Panel Stress in the Area of Node 10 (Nearest the Tunnel Wall)

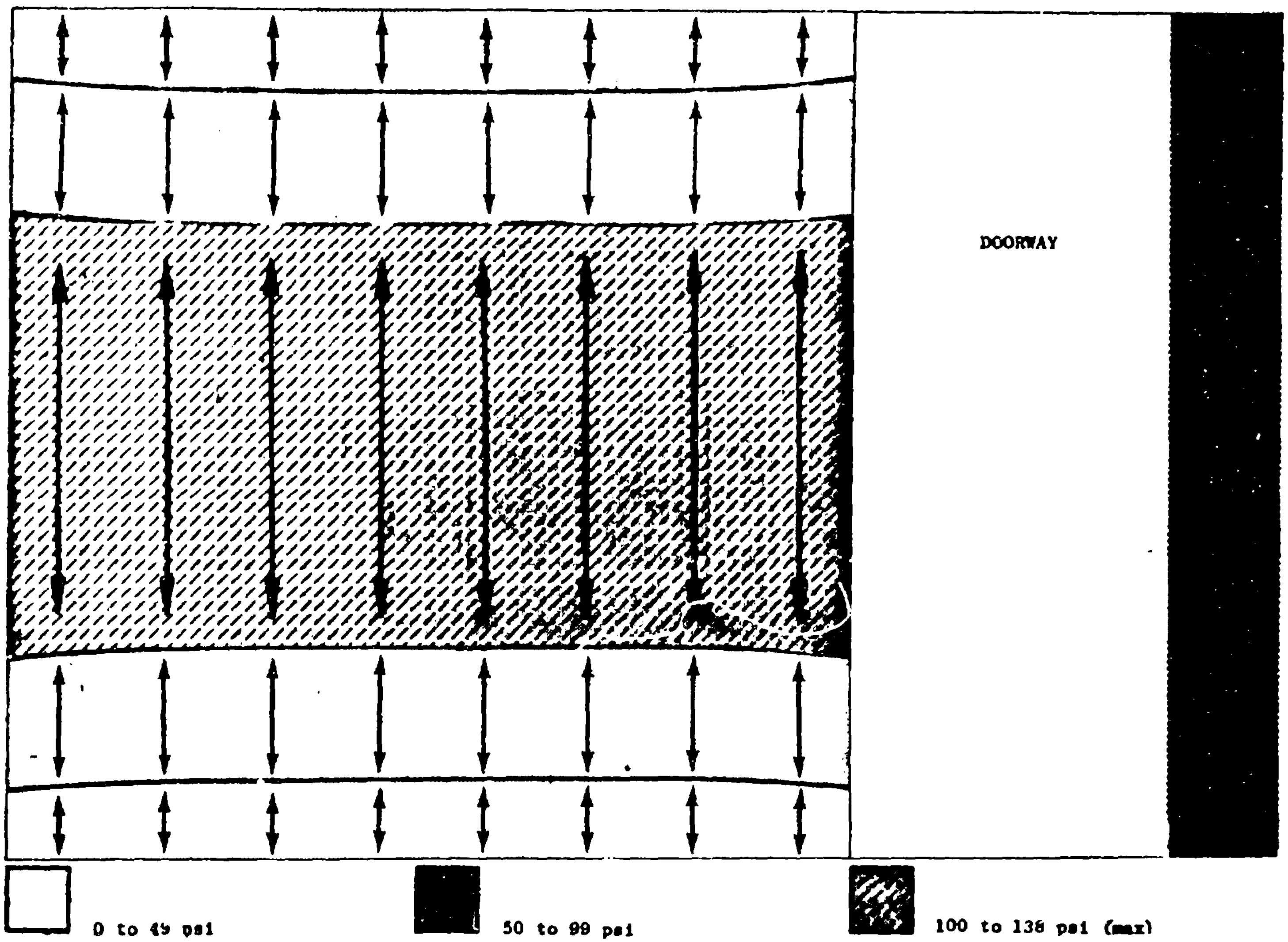


Fig. 14. Wall Stress at t = 0.013 sec for p_r = 1.0 psi.

FULL-SCALE DYNAMIC TESTS

The foregoing provides the input for a test of a full-scale (8 ft high by 8 ft wide by 8 in. thick) brick wall, simply supported top and bottom, with a 3 ft doorway.

From the <u>static test program</u> there is some probability that the wall would have a flexural strength greater than 200 psi (approximately the mode of Fig. 5).

From the <u>dynamic analysis</u> of the structural system, it can be shown that a peak reflected pressure, p_f, of about 1.33 psi is required to provide a maximum stress of 200 psi; hence, to ensure failure on the first excursion we should use a pressure higher than 1.33 psi. Such a wall is shown in Fig. 15.

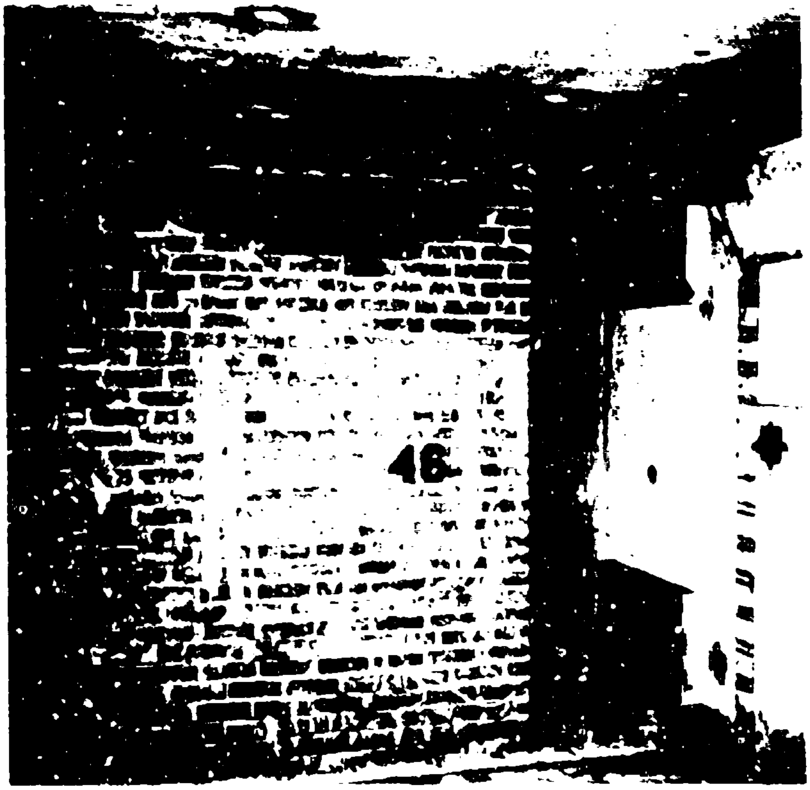


Fig. 15. Pre-Test Photograph of Wall Panel 46

In the actual test two strands of Primacord were used. This provided a lower bound p_f of 3 psi, much greater than that predicted to just fracture the structure. In fact, from Fig. 13 and the allowable static stress, failure could be expected in 6 to 8 msec. Figure 16 below shows the brick wall of Fig. 15 after being subjected to 3.5 psi reflected overpressure.

Fig. 16. Post-Test Photograph of Wall Panel 46

TEST RESULTS

The tests covered in this report are shown in Table 1.

It has been found that the most useful way of organizing and presenting the information from the program is in the form of the "Failure Strength Matrix" shown in Figure 17. Contained in this figure are the geometries, support conditions, materials, and the loading (reflected) overpressures encountered in the test program, plus extrapolations made by the authors to untested conditions. It should be noted that the basic aim of the program was to develop reliable means of predicting the failure strengths of untested geometries (that is, of extrapolating from tested geometries) using a minimum of tests. It was for this reason that the program included material property (static) tests and theoretical investigations as well.

Greater detail on all phases of the program can be found in the series of five reports given in the last section of this paper.

SUMMARY OF SHOCK TUNNEL TEST DATA

1. SOLID WALLS

TEST NO.	INCIDENT OVERPRESSURE P_1 - (psi)	REMARKS
		8-in. Brick Simple Beam Wall
1	1.5	Wall failed completely
2	1.7	" " "
3	1.7	" " "
5	1.8	" " "
7	1.8	" " "
21	1.7	" " "
4	4.3	" " "
6	4.4	" " "
20	4.6	" " "
22	3.5	" " "
		12-in. Brick Simple Beam Wall
50	1.9	Wall failed completely
51	2.1	" " "
52a	0.75	No sign of failure
52b	0.75	" " " "
52c	0.75	" " " "
52d	2.0	Wall failed completely
		8-in. Brick Simple Beam Wall With Preload (To simulate high curtain bearing walls)
64	0.75	Wall cracked full width but did not come out of frame (preloaded to 16,500 lb*)
64	0.75	Wall completely collapsed
65	0.75	Wall completely collapsed (preloaded to 16,500 lb)
66	0.75	Wall cracked full width; did not collapse and not reloaded (preloaded to 23,500**)
81	0.8	Wall cracked (preload to 28,500)
82	0.8	" " " " "
	2.0	Wall failed (preload to 28,500)

*Equivalent to a two-story curtain wall.
**Equivalent to a three-story curtain wall.

SUMMARY OF SHOCK TUNNEL TEST DATA (cont.)

2. WALLS WITH DOORWAY

TEST NO.	INCIDENT OVERPRESSURE P_1 - (psi)	REMARKS
		8-in. Brick Simple Beam Wall With Doorway (20% open)
46	1.7	Wall failed completely
44	4.0	" " "
45	1.8	" " "
48a	0.75	No visible damage
48b	0.75	" " "
48c	0.75	" " "
48d	1.7	Wall failed completely

3. WALLS WITH WINDOWS

TEST NO.	INCIDENT OVERPRESSURE P_1 - (psi)	REMARKS
		8-in. Brick Wall With Window (38"x62")
56	1.8	Wall failed
57a	0.65	Wall cracked
57b	0.65	Wall crack enlarged
57c	0.65	" " "
57d	1.9	Wall failed
		8-in. Concrete Block With Window (39"x62")
60a		"Plink" for period -- cracked
60b	0.75	Wall failed
61a		"Plink" for period -- wall cracked
61b	0.75	Cracks enlarged
61c	0.75	Wall failed
		Preloaded 8-in. Brick Wall With Window (39"x62")
69a	0.8	No damage (preload to 22,500)
69b	2.0	Wall failed (preload to 22,500)
70a	0.8	No damage (preload to 22,500)
70b	2.0	Wall failed (preload to 22,500)

SUMMARY OF SHOCK TUNNEL TEST DATA (cont.)

3. WALLS WITH WINDOWS (continued)

TEST NO.	INCIDENT OVERPRESSURE P_1 - (psi)	REMARKS
		Preloaded - 8-in. Concrete Block Wall With Window (39"x62")
72	0.8	Wall cracked (preload to 22,500)
	2.0	Wall failed (preload to 22,500)
73	0.8	Wall cracked (preload to 22,500)
	2.0	Wall failed (preload to 22,500)
		Arched 8-in. Brick Wall With Window (38"x62")
80	6.0	Wall cracked
	7.5	Wall failed
		Arched Solid Walls
68	.75	4-in. brick beam -- Wall cracked
	2.0	Wall failed
71		8-in. brick beam -- Test for natural period
	2.0	Wall cracked
	3.5	Cracks enlarged
	4.5	Wall failed
74	6.0	8-in. brick beam -- Wall failed
75	6.0	8-in. brick beam -- Wall failed
76	6.0	8-in. brick beam -- Wall failed
77	3.5	8-in. concrete block beam -- Wall cracked
	2.0	No additional damage
	3.5	Wall failed
78	4.5	8-in. concrete block beam -- Wall failed
79	6.0	6-in. concrete block beam with 4-in. brick facing on side toward blast -- Wall failed

SUMMARY OF SHOCK TUNNEL TEST DATA (cont.)

3. WALLS WITH WINDOWS (continued)

TEST NO.	INCIDENT OVERPRESSURE (psi)	REMARKS
		8-in. Brick Simple Plate Wall
24a	1.6	Did not collapse, but severely cracked in yield line pattern
24b	1.5	Wall failed completely
25	1.7	Did not fail completely, but a large piece was removed; severely damaged, so not retested
29a	1.9	Wall did not collapse, but cracked in yield line pattern
29b	2.0	Wall collapsed completely
28	1.9	" " "
23	4.0	" " "
32	3.9	" " "
33	3.9	" " "
		Room With Front Window (62"x33½") and Solid Back Wall
		8-in. Concrete Block Beam
58a		Plink for natural period -- Wall cracked
58b	0.75	Wall failed
59	0.75	Wall failed
		6-in. Hollow Clay Tile Beam
62	0.75	Wall failed
63	0.75	" "

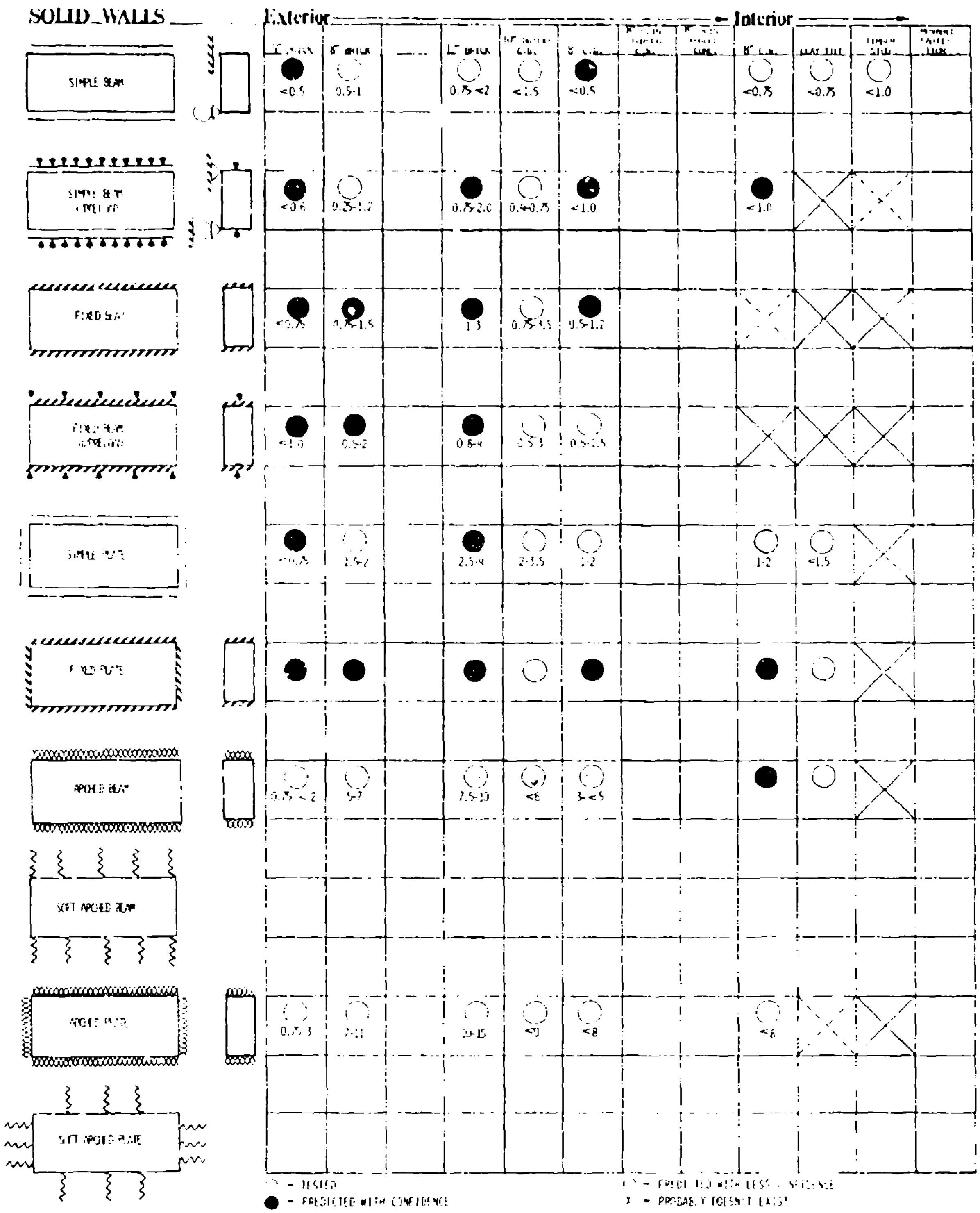


FIG. 17 FAILURE STRENGTH MATRIX - SOLID WALLS

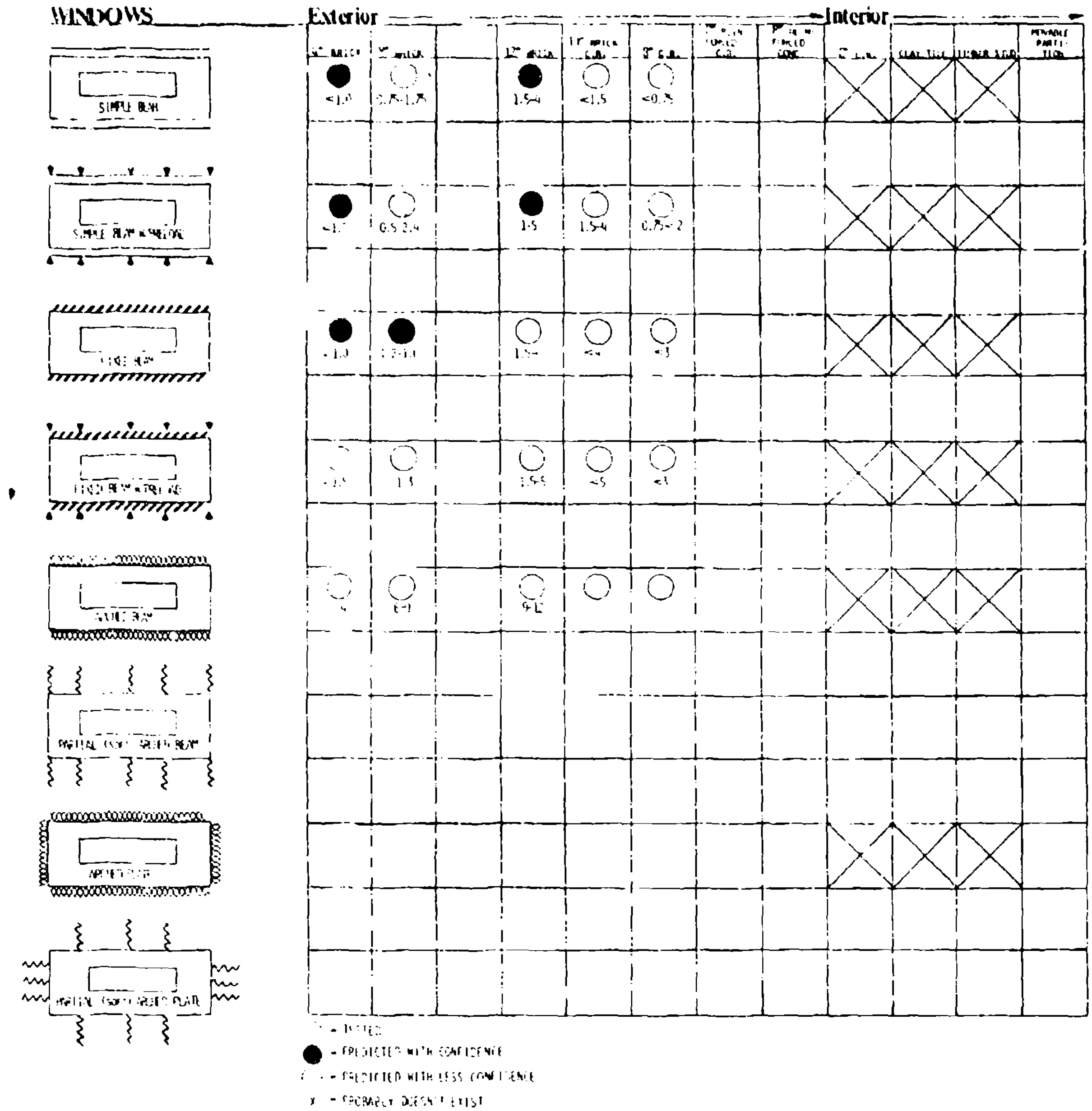
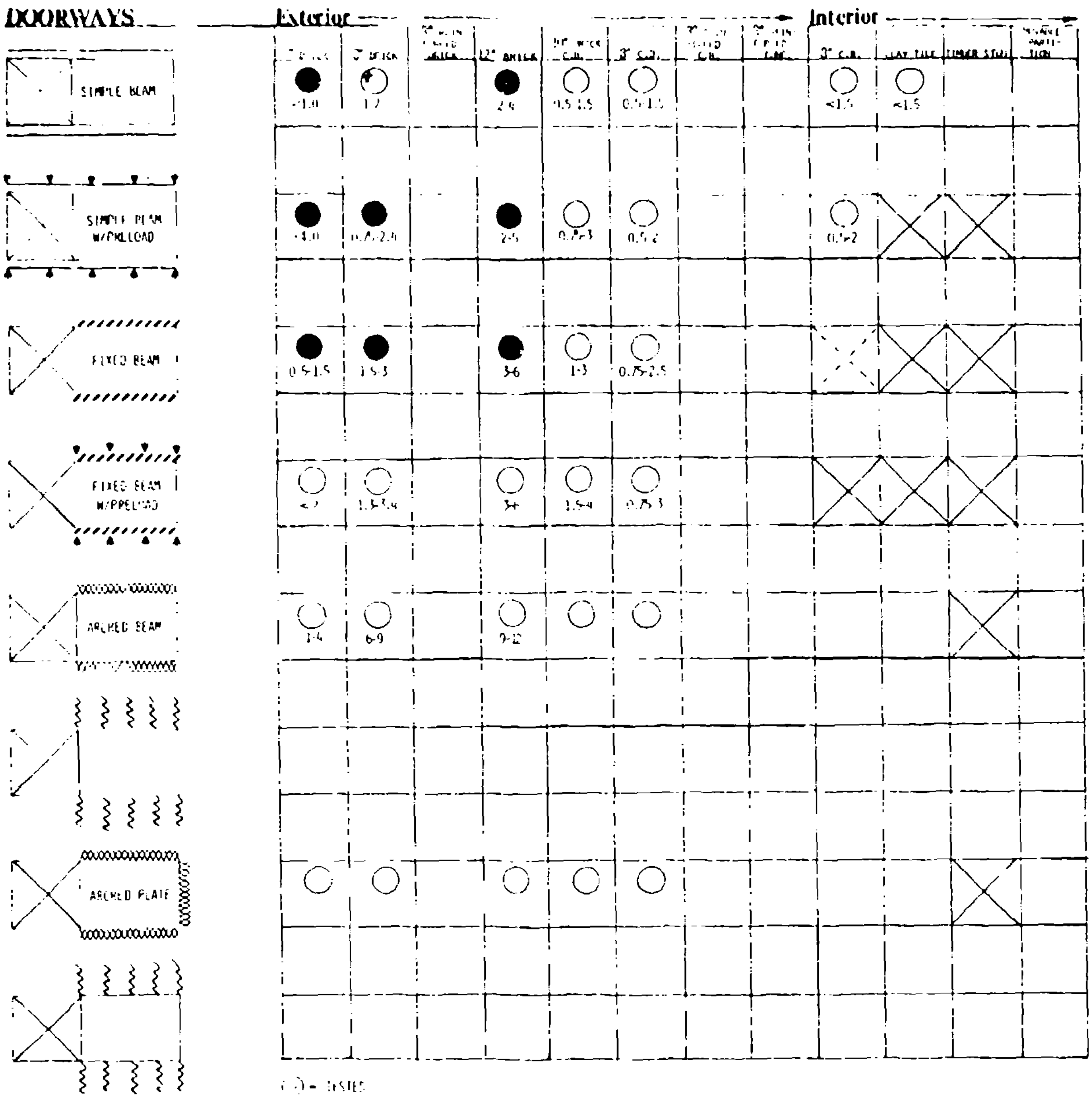


Fig. 17 Failure Strength Matrix - Windows



( ) = TESTED

● = PREDICTED WITH CONFIDENCE

( ) = PREDICTED WITH LESS CONFIDENCE

X = FACADE DOESN'T EXIST

Fig. 17 Failure Strength Matrix - Doorways

REFERENCES

1. Wilton, C., and B. Gabrielsen, Shock Tunnel Tests of Preloaded and Arched Wall Panels, URS 7030-10, June 1973.

2. Wilton, C. and B. Gabrielsen, Shock Tunnel Tests of Wall Panels, URS 7030-7, January 1972.

3. Wilton, C., B. Gabrielsen, and P. Morris, Structural Response and Loading of Wall Panels, URS 709-11, July 1971.

4. Wilton, C., B. Gabrielsen, J. Edmunds, and S. Bechtel, Loading and Structural Response of Wall Panels, November 1969.

5. Willoughby, A. B., C. Wilton, B. L. Gabrielsen, and J. V. Zaccor, A Study of Loading, Structural Response, and Debris Characteristics of Wall Panels, URS 680-5, July 1969.

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* All the listed reports were prepared for the Defense Civil Preparedness Agency (or its predecessor, the Office of Civil Defense) Washington, D.C., 20310, by URS Research Company, San Mateo, California, 94402.

50-MAN BUNKER FOR CLOSE-IN DIRECT OBSERVATION OF ARTILLERY FIRE

by

RICHARD L. WIGHT
OFFICE OF THE CHIEF OF ENGINEERS
DEPARTMENT OF THE ARMY
WASHINGTON, D. C.

ABSTRACT

The Corps of Engineers is designing a semi-buried concrete bunker that will safely absorb a direct hit from a 105-millimeter artillery shell. The purpose of the bunker is to provide shelter for soldiers viewing artillery fire. A unique feature of the bunker is the 11-inch thick transparent plastic windows that eliminates the need for periscopes without exposing soldiers to fragments. The bunker's top, sides, and rear are protected by earth and a burster slab designed to insure ricochet if detonation for some reason does not occur. The front face is designed to resist blast and fragments from a shell detonating at any point on its trajectory. Because of the fragment hazard and large number of persons in a relatively small volume, special ventilating measures are incorporated.

50-MAN BUNKER FOR CLOSE-IN DIRECT OBSERVATION OF ARTILLERY FIRE

I see this paper as direct proof of the value of the Explosives Safety Board's annual seminar. What I am going to present here is a description of a design problem that was in part solved by the information presented in a paper at last year's seminar.

The title of this paper is: "50-Man Bunker for Close-In Direct Observation of Artillery Fire." A more forthright title might be: "How to Keep from Getting Killed in the Impact Area of an Artillery Range."!

The consulting engineer firm of Black and Veatch, Kansas City, Missouri, is designing for the Corps of Engineers a semi-buried concrete structure that will be located in an artillery range impact area and that will absorb a direct hit from a 105-millimeter artillery shell without injuring any of the 50 men inside. In addition, the structure itself must suffer only superficial damage. (Fig. 1)

The purpose of this structure is to provide shelter for soldiers undergoing two types of training. One type of training is simply familiarization with what it feels like to have artillery shells detonating nearby, hopefully no closer than 100 meters.

Another type of training was the basis for a special feature of this design. In order to adjust artillery fire, (that is, to direct the man at the trigger a mile or so away to send the next round right or left, uprange or downrange) you have to see. The only "seeing" permitted by Army Regulations has been through periscopes. This indirect seeing lacks realism, of course, and the realism obtained by viewing bursts directly through slits is too dangerous because of the fragment hazard.

A compromise solution to the realism versus safety issue is a window; a very special window that provides the same degree of safety as the wall it is imbedded in, but yet permits a high degree of realism for training. (Fig. 2)

This window is what I was referring to a few minutes ago when I talked about a direct benefit from last year's seminar. Some of you may recall the paper authored by Mr. J. O. Davis and Mr. P. E. Jockle, Jr., of Sandia Laboratories, entitled, "Design and Development of a Four-Foot by Six-Foot Explosion-Proof Window." That paper described an 11-inch thick laminated window, 4-ft by 6-ft, that would resist the effects of detonating 6 pounds of explosive as close as 5 feet from the window.

Such a concept appeared ideal for our bunker and since our situation will be less stringent, the Sandia design concept was adopted with very little change. I say "less stringent" for the following reasons:

- the explosive equivalency of a 105 shell is 5.6 lbs of TNT, slightly less than the 6 lbs used by Sandia

- the closest a shell can get to the window is 7 feet, but this will be at such an angle that the reflected pressure will not be the maximum that could be expected at that range.

- our windows are much smaller: approximately 3 ft by 1 ft as opposed to 4 ft by 6 ft. Thus the area exposed to blast that must be restrained by the framing is only 1/8 that of the Sandia window.

- and finally, our window is assembled as a wedge, which virtually eliminates any possibility of blast pressure punching the window into the interior of the bunker.

You can see that the window design is quite conservative -- possibly over conservative. It is possible that the 11-inch thickness could be reduced. Also, it is conceivable that the wedge concept might not be necessary.

This point presents, in miniature, one of those classical little engineering judgment situations. For on the other hand, we would not feel confident about 50 men occupying a bunker that contained thinner windows that had not been tested. Then on the third hand, the estimated savings in cost of window materials for the relatively small number of bunkers likely to be built does not warrant an expensive test.

Thus we have the present design: One we have complete confidence in at a reasonable cost.

Here are some of the less obvious features of this particular window design:

- the frame can be inserted in the wall during forming and after the concrete has been poured will be firmly embedded.
- gasketing will keep moisture out of the case and out from between the laminations.
- the frame clamp, in addition to tightening the gasketing, will insure that loose panes are never present.
- since nearly all fragment damage will occur on the outside surface of the window, only one lamination will have to be replaced periodically.
- the clamping bolts will withstand the negative pressure of 6 psi associated with the 105 burst, so that the window can't be sucked out.

The window is assembled - starting from the outside - of six one-inch layers of acrylic plastic (commercially this is Lucite or Plexiglas), followed by a one-inch pane of polycarbonate plastic (commercially this is Lexan or Merlon), followed by three more panes of acrylic, and finally by another pane of polycarbonate. Note that a sheet of the tougher (and more expensive)polycarbonate is used as the final barrier.

This window is 11 inches thick. It is very natural that we should be concerned with its optical qualities. We found that the index of refraction of these transparent plastics is almost the same as ordinary window glass.

A person viewing straight ahead through the window will experience an apparent depth difference of 3.6 inches. This is a constant, which means that at 100 meters downrange, where most shells are expected to land, it will look to the viewer as if the shell were landing at 99.91 meters.

The geometry of the window and wall are such that a person can't look through it at too much of an angle. If the viewer had a 90° field of vision, he could see a front 200 meters wide at the 100 meter range. At the extremes of his viewing angle, refraction would distort the line of sight about 3½ inches laterally, and this would not be apparent to the viewer at that range.

While the window is a unique feature of this structure, it is not the only thing that made the bunker an interesting design problem.

I mentioned earlier that the bunker had to be capable of safely absorbing the direct hit of a 105-millimeter artillery round. In other words, our bunker has to resist the effects of a weapon that's designed to destroy bunkers!

There were a few constraints that make the problem manageable.

One, we knew the kind of round that would be fired. That established the explosive loading -- in this case, a TNT equivalent of 5.6 pounds.

Two, we knew the minimum range of the bunker from the firing point -- 3000 meters. This brackets the terminal ballistics: the speed and angle of the incoming round for various sizes of charge.

Three, we knew the type of fuse. It had a 50-millisecond delay clean-up in case the impact didn't set it off. That figure, coupled with the terminal ballistic data, gave us a handle on the amount of penetration possible prior to detonation.

And four, we knew which direction the round was coming from. This permitted us to orient the bunker so that the windows faced away from the weapon.

(Fig. 3) This figure shows the conditions we ended up designing for:

- Earth penetration below the slab.
- At some point in front of the bunker.
- In contact with the slab over the roof.

The fourth condition is not an explosive situation. It consists of designing the burster slab to ensure ricochet.

Ensuring ricochet is essentially a geometry problem. As projectiles strike resistant surfaces at angles less than 90 degrees, they will approach an angle at which they will ricochet rather than penetrate. Th ngle will vary with projectile velocity. A slow moving round icochet much more readily than a high-velocity one.

Bas on the terminal ballistic data we had, and on the work done by the Air Force Weapons Laboratory in charting a great quantity of empirical data on the subject, we concluded that a slope of 1 vertical on 1½ horizontal, or flatter, would cause ricochet - if the ricochet surface were concrete. With a flat enough surface, we could confidently achieve ricochet in earth. But we didn't wish to take the risk of penetrating the wall of an old crater with that 50-millisecond delay fuse. At our 3000-meter range, a shell could penetrate into earth as much as 12 ft prior to detonating and could conceivably go off against the bunker wall.

What we have ended up with is this:

- The toe of the sloping burster slab is far enough from the rear of the bunker that a projectile exploding at maximum penetration in earth will still be farther away than the 9-1/2 feet minimum that we've calculated is required.

- The front face of the bunker is 15 inches thick and reinforced to resist the purely blast effects of the shell bursting in front of the bunker. This 15-inch thickness is also sufficient to protect against fragment effects.

(To digress momentarily, determining the loading from a shell exploding in front of the bunker was an interesting problem in itself.

The steepest angle at which an incoming round will just clear the bunker is 29 degrees. It is closest to the window (7 feet) when it is about 3½ feet in front of the wall, but the window will feel mainly incident pressure from a detonation. It will feel a full reflected pressure when the shell is directly in front of the window, but by then it is about 15 feet away. It would appear that maximum loading is somewhere in between, where the diminishment of pressure by striking the window obliquely is overcome by proximity to the window.

This curve shows the reflected pressure that the window will feel as the explosion occurs at various points along the trajectory. The curve was prepared based on graphs and formulae in TM5-1300, "Structures to Resist the Effects of Accidental Explosions." (Fig. 4)

The maximum reflected pressure of 157 psi occurs when the shell is 5.7 feet in front of the bunker.)

- A 15-inch thick burster slab, coupled with over 4 feet of earth under it, will protect the bunker roof from blast effects. This thickness is also sufficient to prevent scabbing on the invisible back side of the slab. We don't want any weak spots where a second hit in the same spot could conceivably penetrate. (Fig. 3)

The sloping slab surface is also intended to cause bursting as well as ricochet and it too must not be a potential source of weak spots. Even though this slab is farther away from the bunker wall, the 15-inch thickness was maintained because this surface will receive a greater impact loading from an incoming shell since it is more nearly perpendicular to the trajectory.

That completes my outline of the special structural aspects of the bunker.

I would like to note a few auxiliary features of the bunker design.

- The doors are not blast doors. In fact, they'll be kept open during occupancy for ventilation. They are there to keep "undesirable inhabitants" out of the bunker during long periods of non-use. (Fig. 1)

- There is no electrical service. Incoming power lines would be too susceptible to damage to warrant the expense of installation. Electrical service is a luxury-type item that has been dispensed with.

- Ventilation. This was a problem of some concern with 50 men in a somewhat confined space. A simple gravity system using the doors as air intakes and overhead vents as outlets was devised. We have aimed at approximately 15 cfm per man under normal conditions. (Fig. 5) There was the added problem of the vents being possible sources of fragment entry. Balanced against this was the risk that a complex baffling arrangement would unduly restrict airflow. I think the arrangement shown here avoids both dangers. The offset concrete cover protects both the louvers and the bunker interior from fragments. Outgoing air has to make only a single 90 degree turn. We figure that 2 or 3 of these vents will suffice for a 50-man bunker.

The artillery-fire observation bunker described in this paper was designed to satisfy an Army requirement. However, we envision application of this concept to any problem that requires direct, close-in viewing either of an intentional explosion or of something that might explode accidentally. Possible applications include:

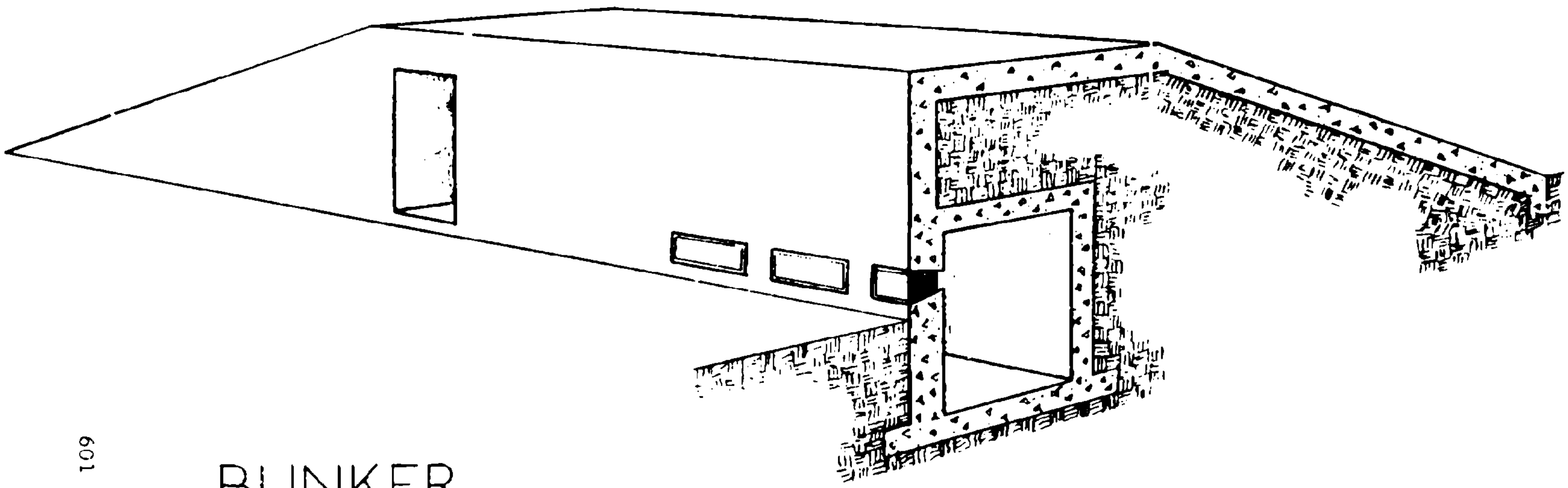
- Training facilities.
- Test facilities.
- Manufacturing facilities.
- Assembly facilities.
- Disassembly facilities.
- Inspection facilities.
- Demonstration facilities.
- Maintenance facilities.
- Research facilities.

We are preparing our design as a standard plan which means that with slight alterations and adjustments, it can be adapted to any location. It can also be adopted to accommodate more or less than 50 men merely by increasing or decreasing the number of 4-foot window segments.

Our design should be completed by the end of this year. We expect to see a bunker built and in use sometime next year.

That completes the formal part of this presentation.

(The views of the author do not purport to reflect the position of the Department of the Army or the Department of Defense.)



BUNKER

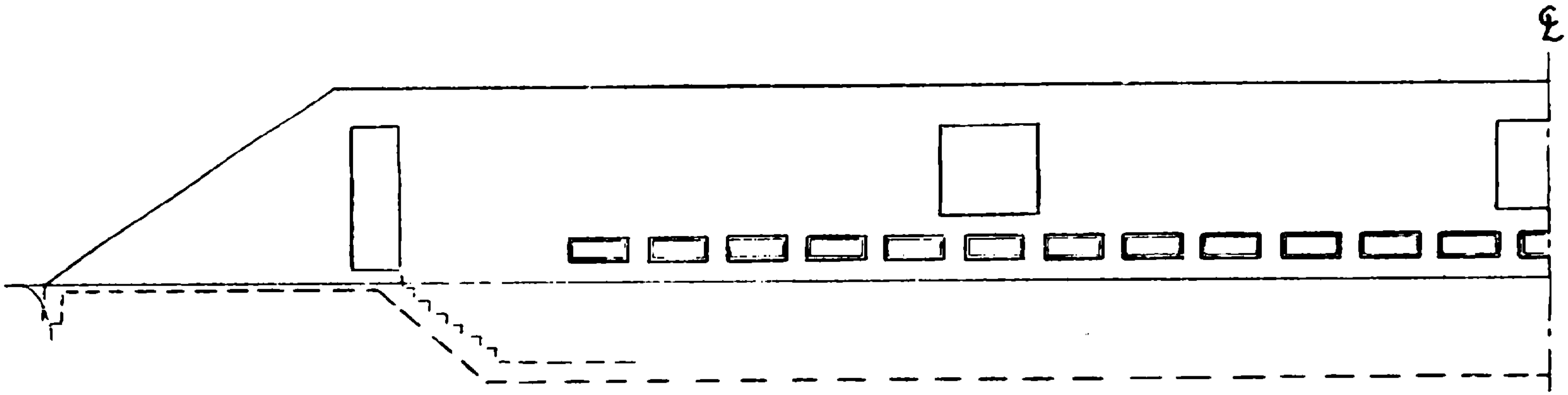
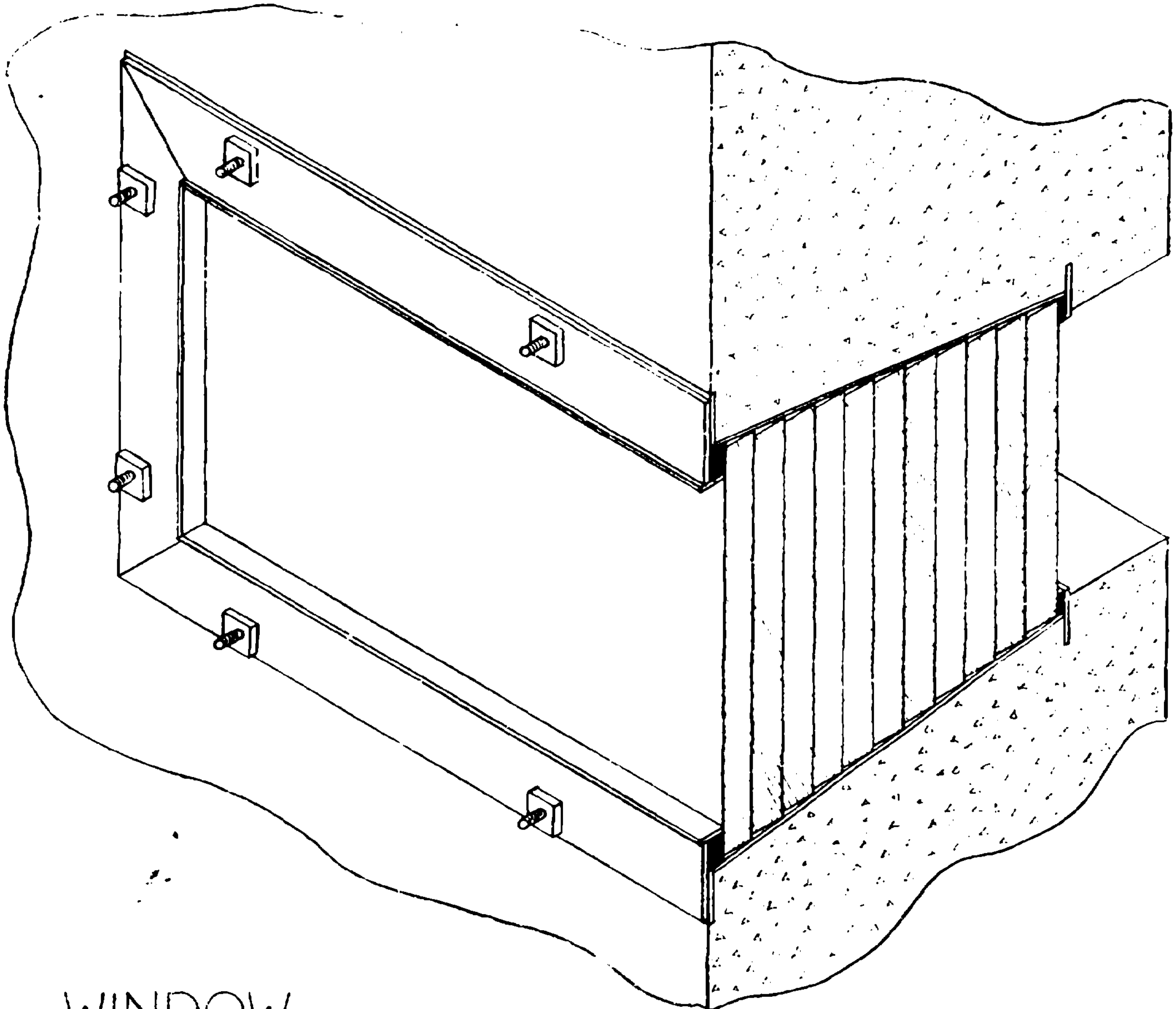
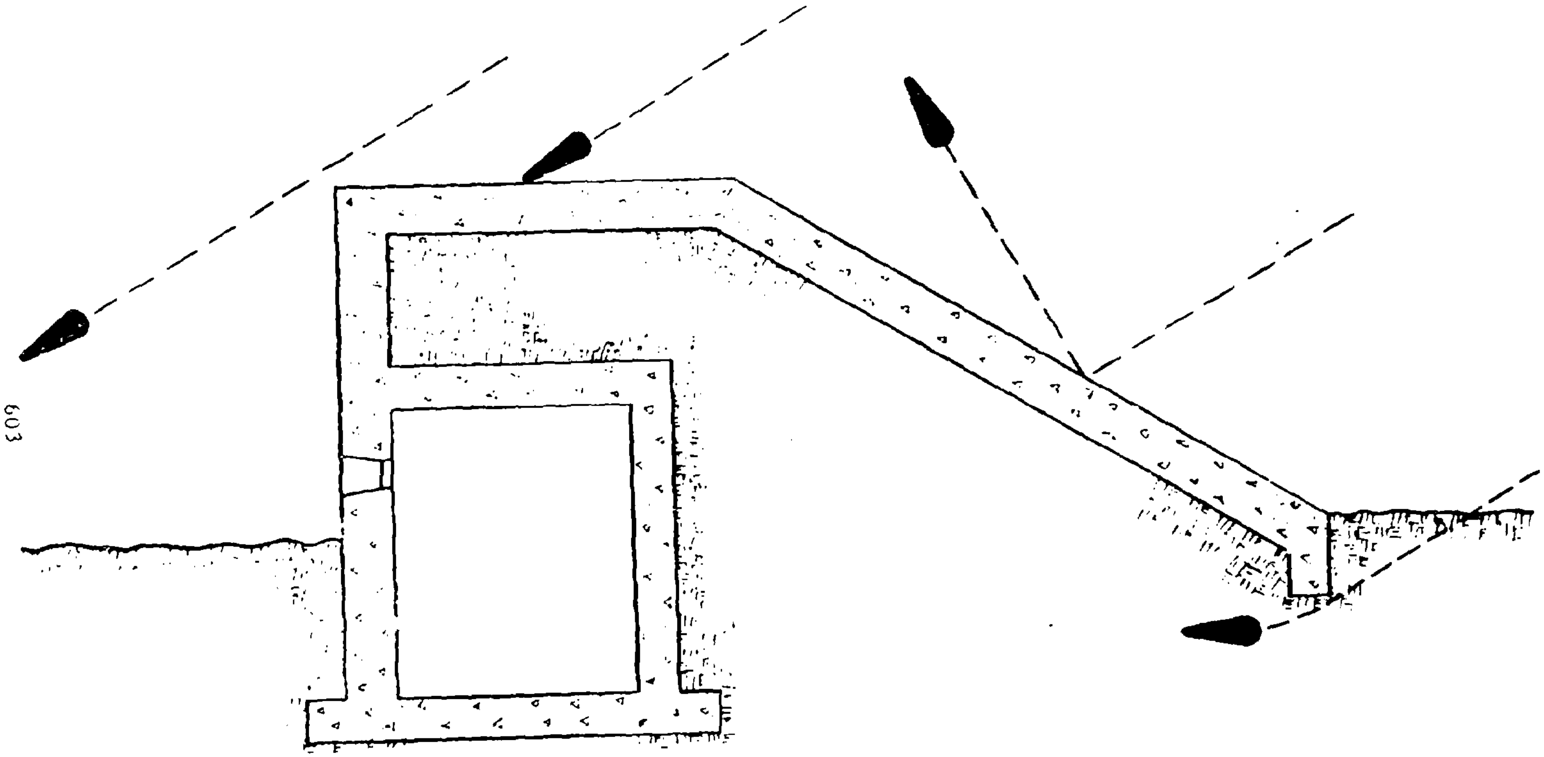


FIG 1



WINDOW

FIG 2



DESIGN CONDITIONS

FIG 3

PRESSURE ON WINDOW

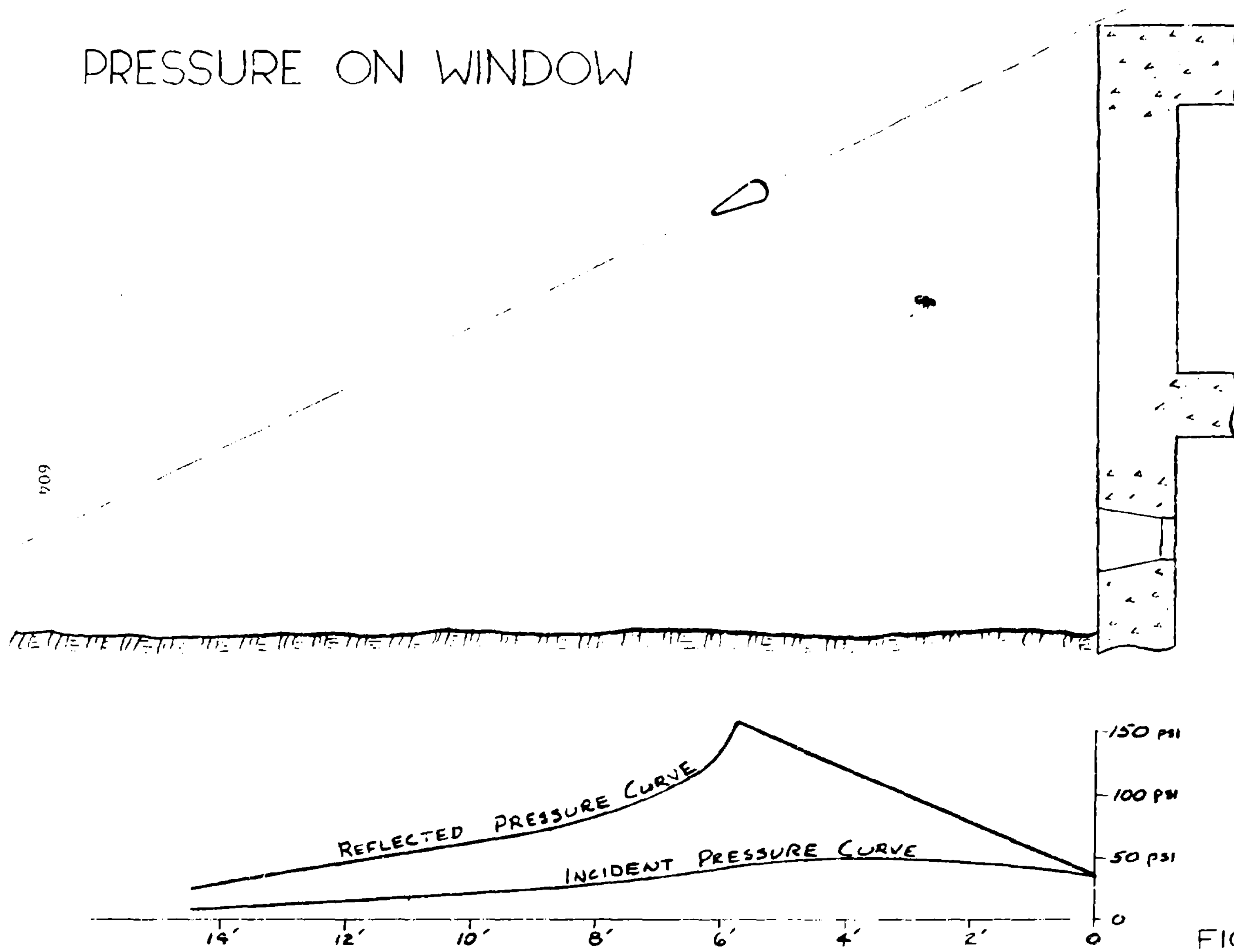


FIG 4

VENTILATOR

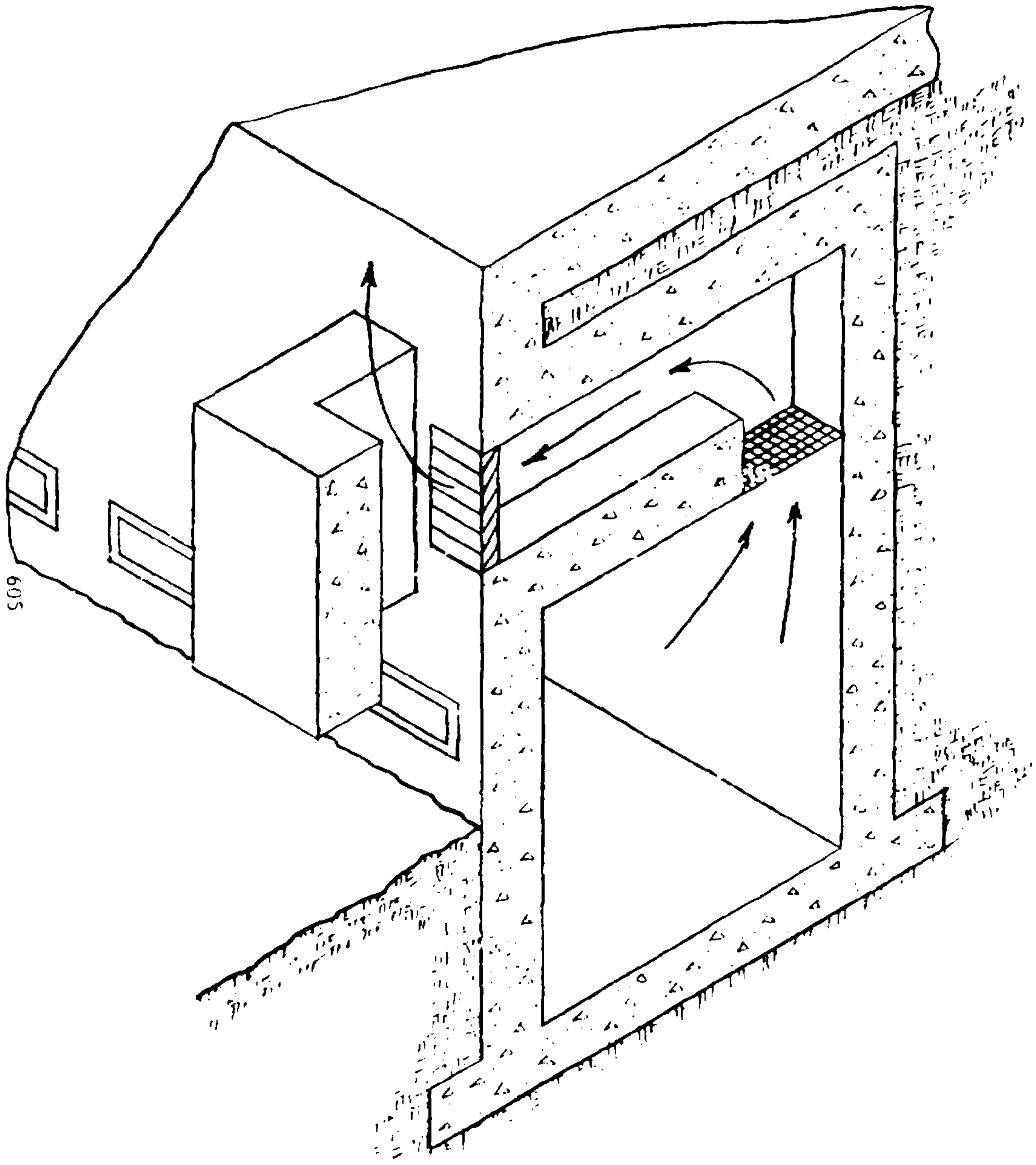


FIG 5

DESIGN OF HAZARD CATEGORY III

PROTECTIVE BARRIERS

E. Cohen and N. Dobbs
Ammann & Whitney, New York, N. Y.

ABSTRACT

Presented are the safety requirements to be considered in the design of "Hazard Category III" operating-station protective barriers. A typical example of an "on line" protective shield capable of withstanding the overpressure and fragment effects associated with explosive quantities as large as 30-pounds of High Explosive (H.E.) is included. Described also are details of closures for equipment and personnel access openings, electrical and mechanical wall penetrations, and methods used for protecting personnel outside of the shield.

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INTRODUCTION

Modernized assembly portions of Load-Assemble -Packout (LAP) facilities of small end-items such as 81mm projectiles, 2.75-inch rockets, etc. will necessitate the positioning of hazardous operations next to some less hazardous operations. Therefore, present safety regulations (References 1 and 2) of the U.S. Army Armament Command (ARMCOM) require that all high hazard (hazard Category III) operating stations be shielded to protect personnel and equipment at adjoining stations.

The use of "on-line" protective barriers (also referred to as shields) are usually cost effective for explosive quantities in the order of 30-pounds of H.E. or less. For larger quantities, the use of separate structures is generally a more economical arrangement. In all cases, however, the hazardous operations, both on-line and in separated structures, must be monitored remotely.

This paper describes several such facilities as well as criteria which may be used for other barrier designs. Both the criteria and the protective barrier were developed for the Manufacturing Tecnnology Directorate of Picatinny Arsenal as a part of their Modernization Assistance Program for ARMCOM.

DESIGN CRITERIA

Hazard Category III operating shields may be constructed either of reinforced concrete and/or structural steel. For smaller charge weights, say 10-pounds or less, the use of structural steel is more cost-effective while with larger explosive quantities,a combined use of steel and concrete is more efficient. A shield must be designed such that all fragments produced by the break-up of an item-casing or equipment are fully contained and that blast leakage pressures are reduced to a level which will not injure personnel or damage other equipment. One method to achieve the required protection is to fully enclose the hazardous operation. However, venting will be necessary to relieve gas pressure build-up due to the explosion confinement. This may be achieved by extending a vent stack from the shield through the roof of the operating building and permitting the blast pressures to be vented to the atmosphere.

The results of some recently performed tests (Reference 3) have indicated that if the diameter of the stack opening is restricted to 15 inches and the stack extensions above the roof of the operating building to those dimensions illustrated in Figure 1 and Table 1 then the leakage pressures acting on the exterior of the roof will be less than 1.2 psi which is the available strength of most conventionally designed metal deck buildings. Although the stack extensions of Figure 1 are representative of gable roof buildings, they are also applicable to flat roof structures. Here, the stack height which is measured above the point where stack penetrates the roof should be used as the stack height criteria for flat roofs. It may be noted that the

increase of the stack height above the roof is equal to one foot per pound of explosive increase.

In addition to the stack height criteria mentioned above for the gable roofs, a stack must also extend above the peak of the roof by a specified minimum height (Figure 1). The roof peak height requirements for a stack will govern when a lower stack height is required for the point where the stack penetrates the roof. As may be seen from Figure 1, the stack height above the peak for a 30-pound charge is 15 feet. For smaller charge weights the minimum height may be reduced one foot for each one-pound reduction in the charge weight.

In the event the strength of the roof is 2.4 psi which is the strength of most existing wooden buildings, the height of the stack can be reduced, i.e. for 30-pound explosive charge, the height of the stack above roof at the point where it penetrates the roof may be reduced to 15 feet. However, for gable roofs, the stack should at least be extended up to the roof peak. For a 15-pound charge, the above height may be reduced to 2 feet. No reduction in stack height is allowed for charge weights less than 15-pounds.

The above discussion applies to explosive quantities equal to or greater than 2-pounds. When the explosive weight equal to or less than 2-pounds is involved, then the size of the stack opening may be increased. For very small charge weights, the size of the opening could be as large as the plan area of the shield. That is, the side walls of the shield would extend above the roof by at least 2 feet with the roof of the shield consisting of only a

weather cover. For those operating buildings having a roof capacity less then 2.4 psi, it is recommended that the 15-inch diameter stack arrangement be used for all charge weights.

The data relating to stack requirements of Table 1 are also applicable to barriers located immediately adjacent to an operating building (Figure 2). Here the vent stack is directed away from the front of the shield thereby directing it away from the operating building. The overall length of the stack, as specified in Table 1, may be reduced by an amount equal to the width of the barrier.

CASE I - ON-LINE PROTECTIVE BARRIER

This case study describes the on-line barrier which will be used to isolate Hazard Category III operating stations from other less hazardous operations in a modernized manufacturing facility for the 2.75 inch rockets. The operating line will be housed in an existing wooden frame building. Except for the protective shield,the moderization of the operation consists essentially of new equipment acquisition.

The protective barrier contains six rockets at any one time, with each rocket containing five-pounds of Composition B explosive. Because data is not available regarding the safe separation to prevent propagation between two adjoining 2.75-inch rockets in confined quarters, the design of the barrier consideres the combined explosive effects of all six items (30-pounds).

Facility Layout

The barrier is a cubicle type structure having interior dimensions of 6 ft.-3 in. width by 12 ft.-0 in. length and 8 ft.-0 in. height (Figure 3). The shell of the barrier consists of four laced concrete walls, a laced concrete roof and an unlaced concrete floor slab. The wall thicknesses are:

Side walls	-	2 ft. -6 in.
Back wall	-	2 ft. -6 in.
Front wall	-	3 ft. -0 in.
Roof and Floor	-	2 ft. -0 in.

Personnel and equipment access into the barrier is through an opening in the front wall. This opening is sealed during the performance of the hazardous operation by a structural steel blast door.

The barrier is oriented such that the longitudinal axis of the barrier is positioned perpendicular to the axis of the explosive item conveyance system; thereby requiring openings in the side walls for access and egress of the rockets. These openings are also sealed during the operation by structural steel blast doors.

The conveyance system consists of chain driven power free conveyor. Two rockets are attached to a pallet which in turn is mounted on tracks. The chain is located below the pallet and between the tracks. The conveyance system is so arranged that the pallets with the rockets are situated on the top while the empty pallets are returned to the loading stations below the pallets containing the rockets. This system requires a tunnel through the barrier. This tunnel isolates the empty pallet return system from the barrier proper and, thereby, prevents the pressure produced by an explosion within the barrier from escaping into the operating building.

As described previously, the 2.75-inch rocket barrier is equipped with a vent stack which allows internal blast pressures to escape to the atmosphere. The stack penetrates the building roof for a height above the roof equal to 15-feet. In this case, the operating buildings roof is capable of resisting a short duration blast load having a peak blast overpressure of 2.4 psi. The stack is formed from 15-inch (I.D.) schedule 40 structural steel pipes.

Personnel Blast Door

The personnel blast door consists of 2-inch structural steel plate which swings inward in an open position; and bears against the interior of the front wall in a closed position (Figure 4).

To prevent the door from opening as a result of an explosion, the door is equipped with six 4-inch diameter reversal bolts. The wall adjacent to each bolt is provided with a recess to accept the bolt when the door is in the "locked" position. A reversal bolt operating mechanism is provided to insert and retract the bolts from their recesses. The bolts are designed to resist both the reversal of the door produced by the positive pressures as well as the negative phase overpressures.

Details of the reversal bolts are illustrated in Figure 5.

Item-In and Item-Out Doors

The openings used for item access and egress to the barrier are "Tee" shaped (Figures 3 and 6). The top section of each opening is 2 ft-0 in. wide by 4-inches high and is that portion of the opening through which the rocket in a horizontal position passes through the walls. The stem of the opening is the section through which the rocket pallet moves. Both the structural steel conveyor tracks and the housing for the drive chain pass through the stem of the opening. The tracks consist of upper and lower sections between which pass the conveyor wheels. Upper sections of the track prevent the conveyor pallet from overturning due to the eccentric forces produced by the non-alignment of the rocket's center of gravity with that of the pallet.

Each door consists of a series of four structural steel plates which are 2-inch thick. The door is mounted on the interior surface of the cell wall

and is capable of resisting both the direct effects of the blast output and the rebound effects. The individual sections of the door move in a plane parallel to the wall. Movement of each portion of the door is controlled by double-action spring-loaded (fail-safe) air cylinder. The cylinders which are also mounted on the interior surface of the wall are protected from the blast and fragments by steel shields (not shown in Figure 6).

Two sections of the door move vertically, the upper section extends down to the bottom of the drive chain housing, while the lower section seals the section of the opening below the housing. The two side sections of the door seal the spaces between the upper and the lower rails of the tracks. The upper section is moved vertically upward with the use of a rotary actuator "flo-tork". A portion of the weight of the door is offset by a counterweight weighting 50 pounds less than that of the door. The other three sections of the door are operated by the air cylinders. Because the chain drive is a continuous operation, a space in the door is required for passage of the chain. The area of chain drive opening is approximately one square inch; although the chain will occupy approximately one half of the open area. The size of the opening is such as to minimize the pressure out of the hole to a level which will not be injurious to operating personnel.

Spall Plates

The internal blast loads will produce a shock in the concrete which will tend to spall off the concrete cover over the reinforcement at the outside of the barrier. To protect personnel immediately outside the barrier, 1/8-inch thick spall plates have been mounted on those exterior surfaces of the structure.

The spall plates are attached to the barrier with a series of structural steel channel sections and anchor bolts (Figure 7). The bolts extend into the wall and are anchored to the flexural reinforcement at the exterior surface of the wall. Tests have shown that if the bolts are passed completely through the wall, the shock wave will pass directly through the bolt and in some instances disengage the head of the bolt at the exterior. This would disengage the spall plate and release the concrete cover over the reinforcement as secondary fragments.

CASE II - CHEMICAL CELLS

Certain in-process operations of a production facility may be explosive in nature. However, because of the nature of the overall production requirements, the positioning of the explosive operations in close proximity of the nonexplosive operations may be a necessity. Therefore, the facilities servicing the explosive operation must be designed to provide full protection for operating personnel and equipment associated with the non-hazard operations.

This case study describes such a facility, where four chemical cells are used for performing certain potentially explosive experiments, adjoining a laboratory building (Figure 8). The cells are designed to contain fully both the blast and fragment effects of an internal explosion and provide controlled venting of the residual internal pressures without damaging the laboratory building and corridors which surround the cells.

Facility Layout

The four chemical cells housed in a single reinforced concrete structure are positioned against the laboratory building (Figure 8) with the back wall of the cells forming a portion of one of the exterior walls of the laboratory. The remainder of the cells are enclosed by an access corridor. The laboratory building is constructed of corrugated metal siding and roof decking while the walls and the roof of the corridor are constructed of concrete block and metal decking, respectively.

The four reinforced concrete cells (Figure 9) are placed side by side with each having an inside length of 12 ft.-0 in. and height equal to 10 ft-0 in. The widths of the individual cells are:

Cell Nos. 1 & 2	- 6 ft.-0 in.
Cell No. 3	- 12 ft.-0 in.
Cell No. 4	- 8 ft.-0 in.

The side by side arrangement of the cells allows for the use of a common back wall, front wall, roof and floor slabs; while the side walls separate the structure into individual cells. All reinforced concrete components are constructed monolithically forming an integral unit. The roof and floor slabs, back wall, and two side walls of the Cell No. 3 are all 1 ft.-8 in. thick; whereas the side walls and front walls of the remaining cells are 1 ft.-6 in. and 2 ft.-4 in. thick, respectively. The thicknesses of the concrete and the amount of reinforcement provided for the individual elements are sufficient to guarantee the structural integrity and to limit the structure's response to deflections which would result from support rotations of less than two degrees. This will permit reuse of the structure in the event of an explosion in any one of the individual cells. The cells are designed to resist the following quantities of TNT:

Cell Nos. 1, 2 and 4	- 5 pounds of TNT
Cell No. 3	- 15 pounds of TNT

Typical reinforcement is illustrated in Figure 10.

The personnel access doors are similar to those described for the barrier of Case I, except that 1-3/4-inch structural steel plates are required.

Figures 11, 12 and 13 illustrat installation of the personnel blast door.

Spall plates similar to those previously described were also used for protection of personnel. Here, the control panel for the cell operation is located in the laboratory immediately behind the cells.

Ventilation is achieved through intake and exhaust ducts located at the front of the cells. Each duct is 8-inch (I.D.) schedule 40 structural steel pipe which extends out over the corridor located at the front of the building. The pipes also served as vent stacks for venting the effects of an internal explosion. Because of the requirement to extend the vent pipe past the corridor, the distance between the laboratory and the end pipes is greater than that specified by Table 1.

Electrical and Mechanical Penetrations

Controls for operating the equipment within the cells are located in the Laboratory Building and, therefore, penetrations through the cell walls are required to allow for access of electrical and mechanical lines. Each penetration consists of pipe sleeve with a coupling attached at each end and a steel plate flange welded near the center of the sleeve (Figure 14). The flange is located in the concrete wall and, thereby, will prevent the pipe sleeve from being projected out of the wall as a result of the blast or fragments produced by the internal explosion. Sealing of the electrical penetrations is achieved by attaching a pressure tight "gland" at each end of each penetration. Mechanical arms which also penetrate the walls are provided with glands. Electrical penetrations extend through all exterior walls of a cell whereas mechanical arm penetrations are only located in the back wall of cells (side of cells facing the Laboratory). All hydraulic lines are located in the front wall of the cells (side with corridor). Each hydraulic line going out from the cell continues across the corridor and through the

corridor wall to the exterior where it terminates. A rupture disk is located at the exterior end of each hydraulic line. Within the corridor each hydraulic line coming out of the cell makes a turn and proceeds along the corridor and into the Laboratory Building. Immediated after the first turn, each hydraulic line is provided with an automatic shut-off valve; which in the event of an explosion will be triggered by a sensing device in the cell. Leakage pressures from the cell will force the liquid in the hydraulic line to fail the rupture disk and thereby relieve the blast pressure to the atmosphere.

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1. Safety Manual, AMCR 385-100, Headquarters, U.S. Army Materiel Command, April, 1970 (Revised April, 1971)

2. Dobbs, N., Approved Safety Concepts for Use in Modernization of USAMUCOM Installations, Technical Report 4429, Manufacturing Technology Directorate, Picatinny Arsenal, Dover, New Jersey, October 1972.

3. Ferritto, J.M., Determination of Blast Leakage Pressures and Fragment Velocity for Fully Vented and Partially Vented Protective Cubicles, Technical Report R780, Naval Civil Engineering Laboratory, Port Huenene California, 93043, November 1972 (Revised August 16, 1967).

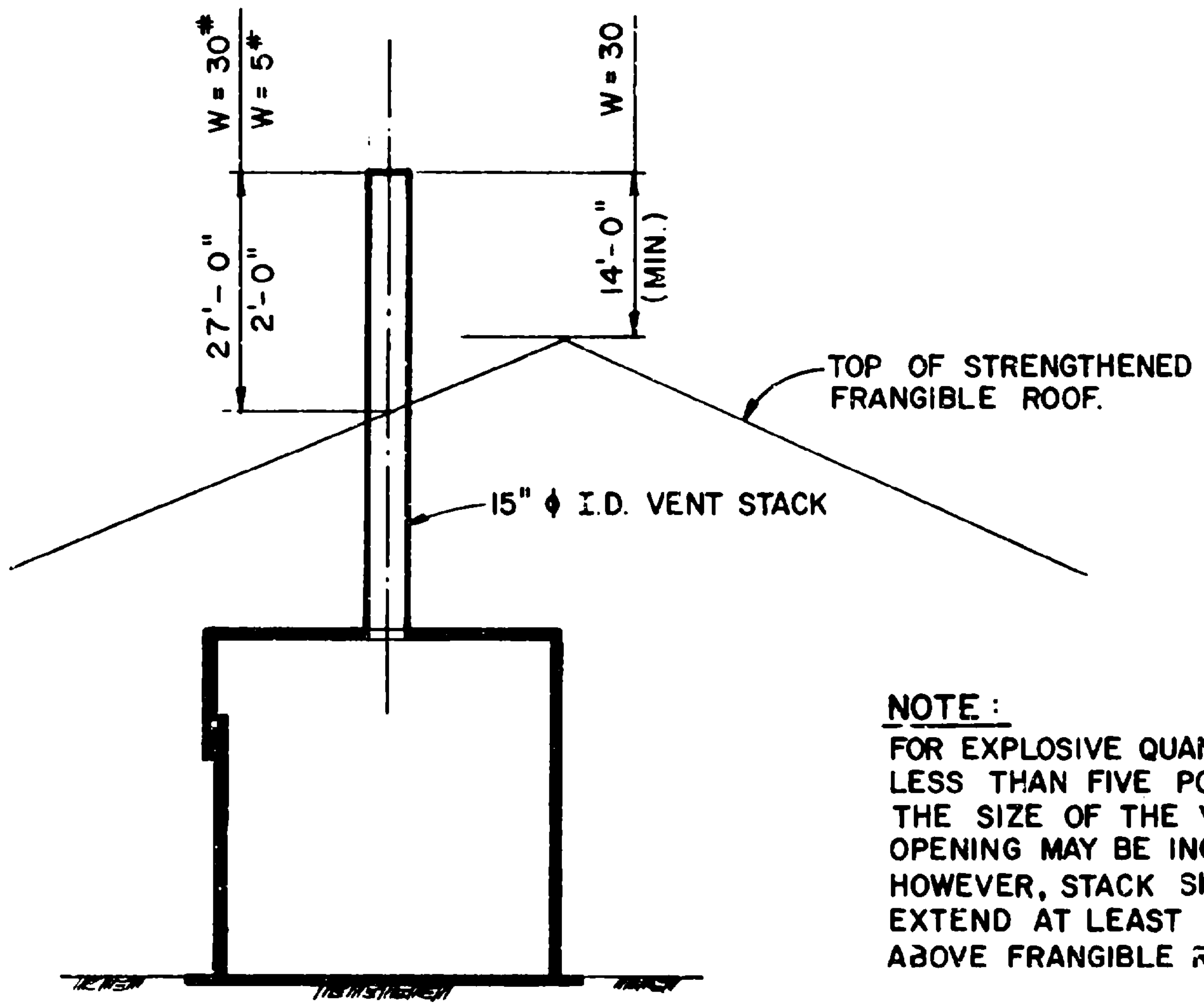
TABLE 1

DESIGN CRITERIA FOR VENT STACKS

Building Type	Capacity of Oper. Bldg. Roof (psi)	Diameter of Stack Opening (in.)	Charge Weight (lbs.)	Height of Stacks (ft.) Flat Roofs	Gable Roofs Abv. Stack Penet.	Gable Roofs Abv. Roof Peak
Convent. Design Metal Deck Buildings	1.2	15	30	27	27	15
			15	12	12	0
			5	2	2	N.A.(2)
Strengthened Metal Deck and Exist. Wood Frame Buildings	2.5	15	30	15	15	0
			15	2	2	N.A.
			5	2	2	N.A.
		(1)	2	2	2	N.A.

(1) Walls of the shield extend above the roof of the operating buildi..

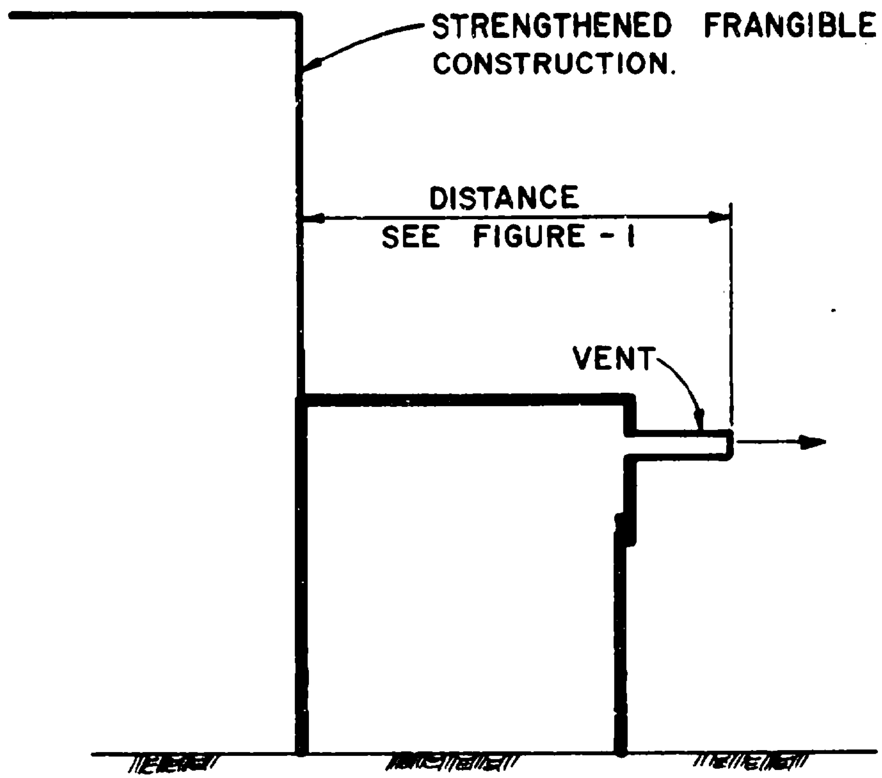
(2) N.A. = Not Applicable.



NOTE:
FOR EXPLOSIVE QUANTITY LESS THAN FIVE POUNDS, THE SIZE OF THE VENT OPENING MAY BE INCREASED HOWEVER, STACK SHALL EXTEND AT LEAST 2 FT. ABOVE FRANGIBLE ROOF.

ELEVATION

FIGURE 1
CRITERIA FOR HAZARD CATEGORY III OPERATIONAL RARRIER



ELEVATION

FIGURE 2
HAZARD CATEGORY III SHIELD ADJOINING OPERATING BUILDING

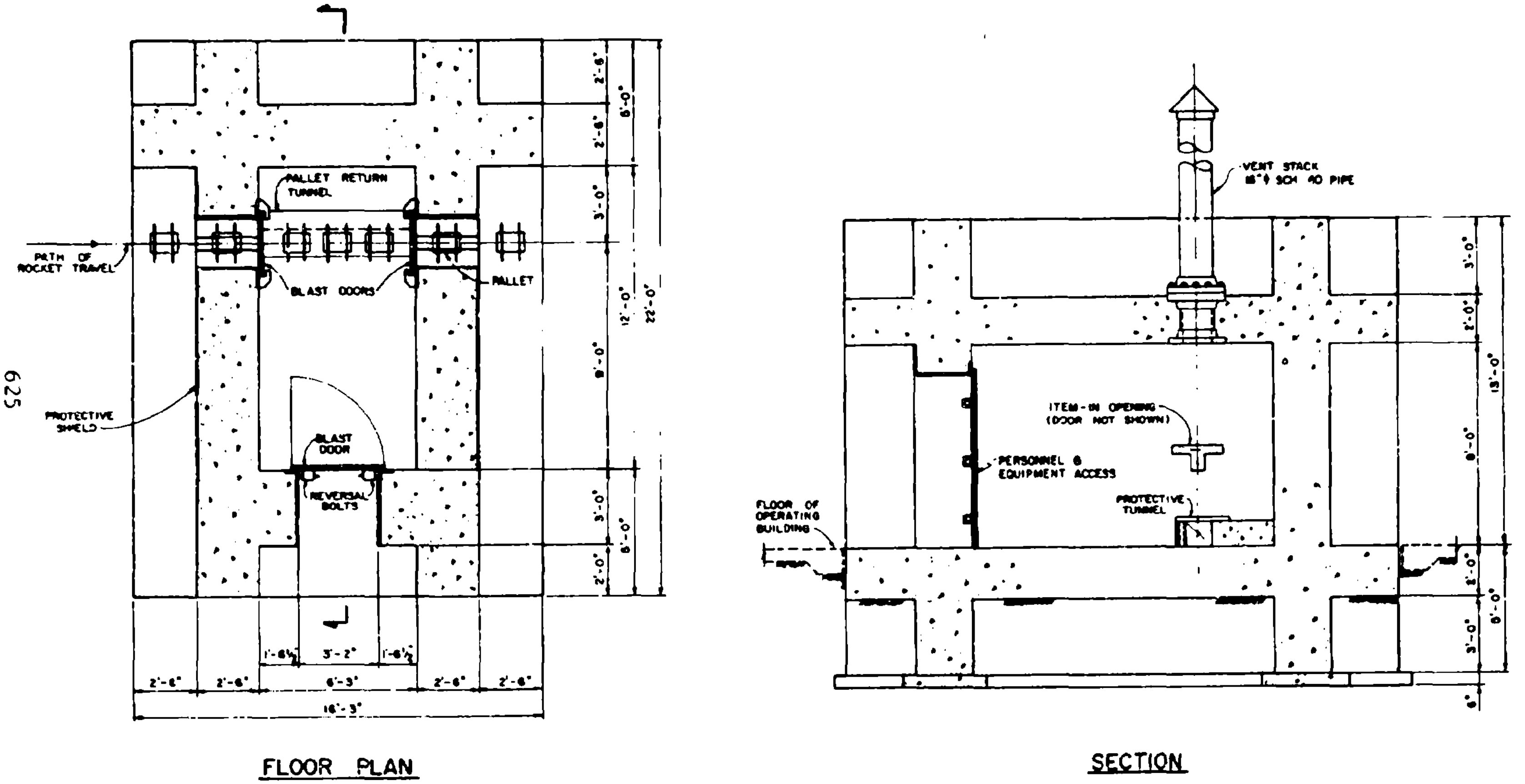


FIGURE 3
CASE STUDY I - ON-LINE PROTECTIVE BARRIER

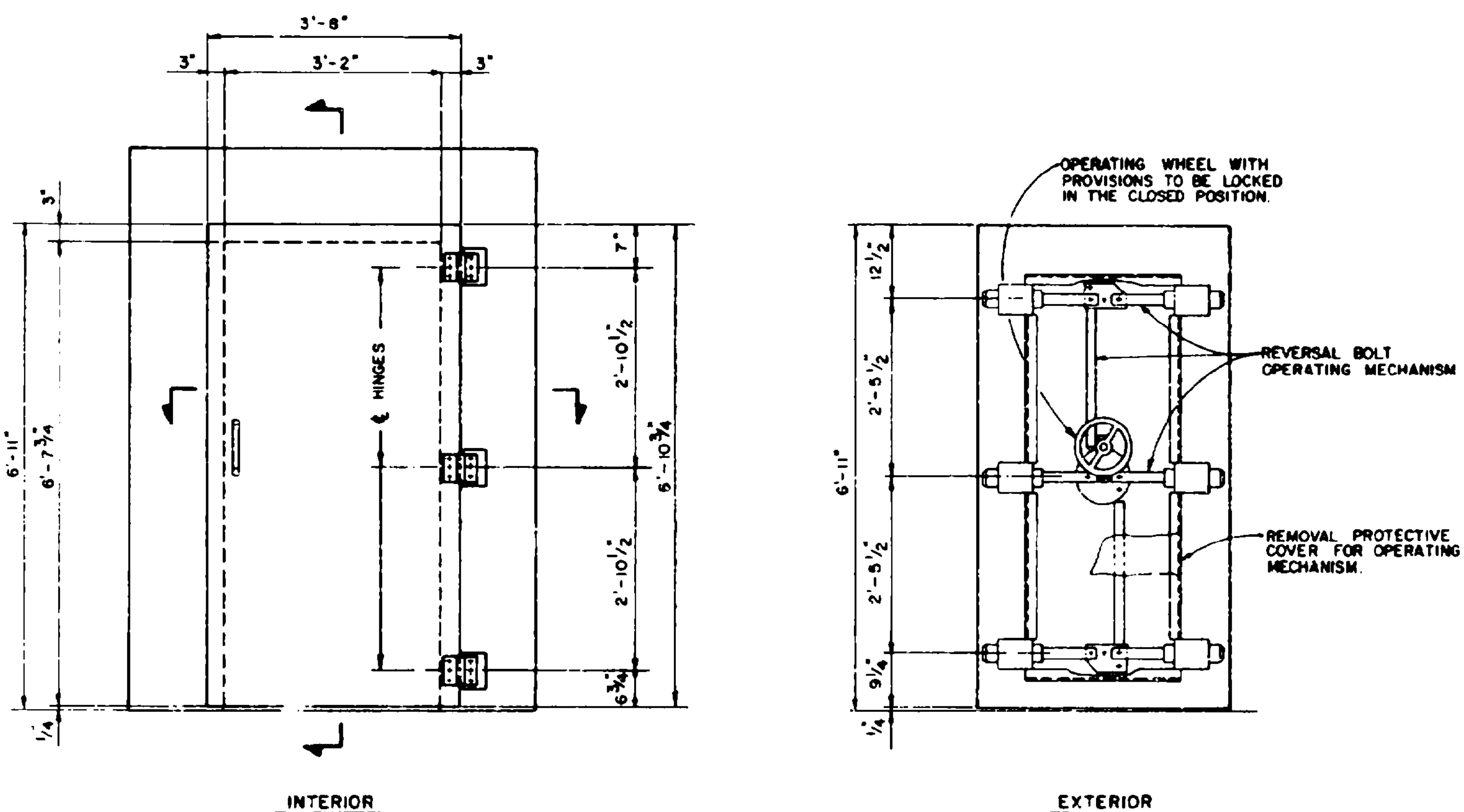


FIGURE 4
PERSONNEL BLAST DOOR ELEVATIONS

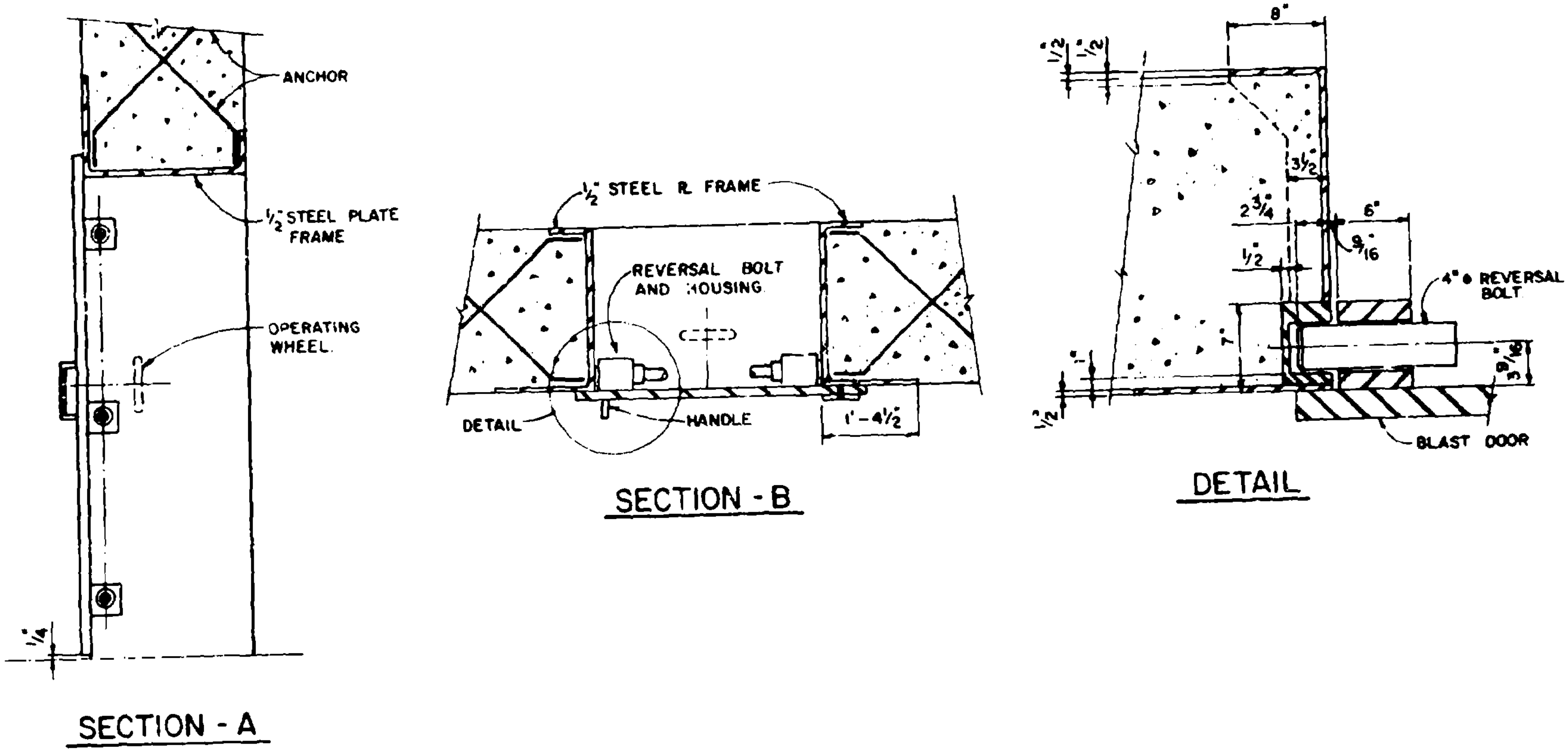


FIGURE 5
REVERSAL BOLT MECHANISM DETAILS

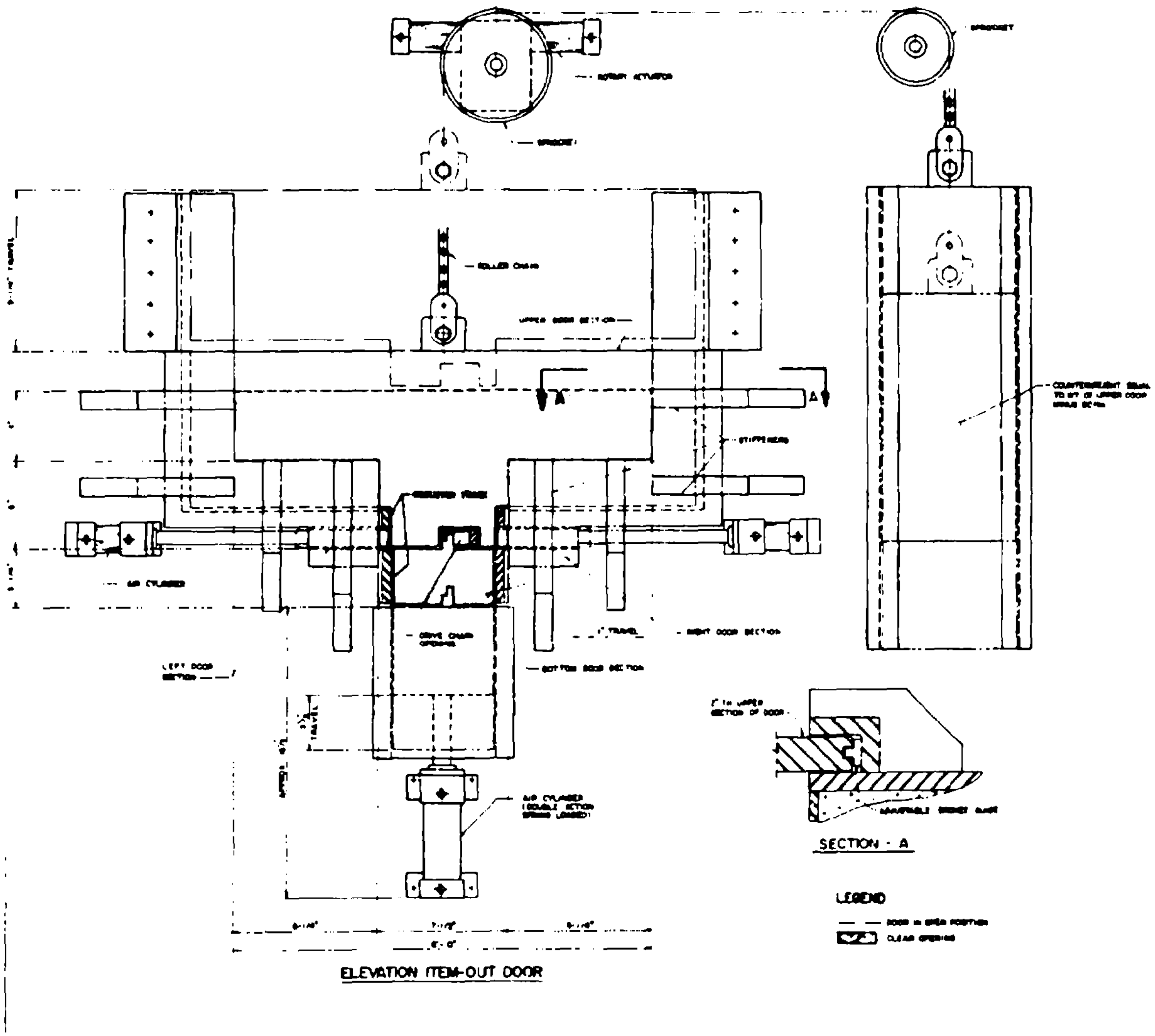


FIGURE 6
ELEVATION OF ITEM-IN AND ITEM-OUT DOORS

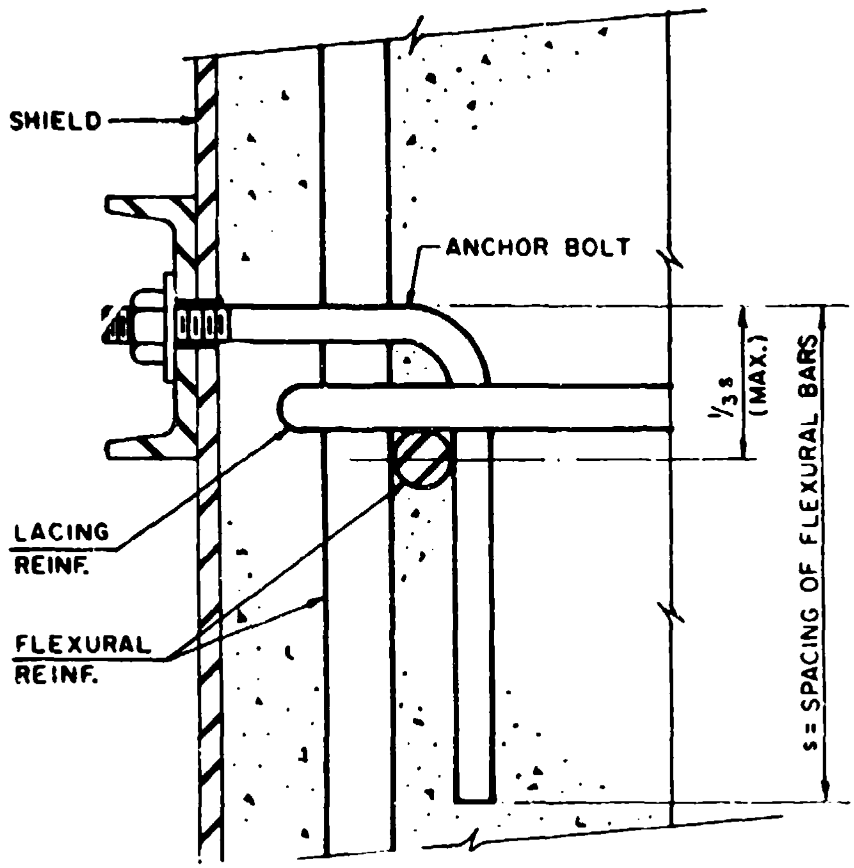


FIGURE 7
DETAIL OF SPALL PLATE CONNECTION

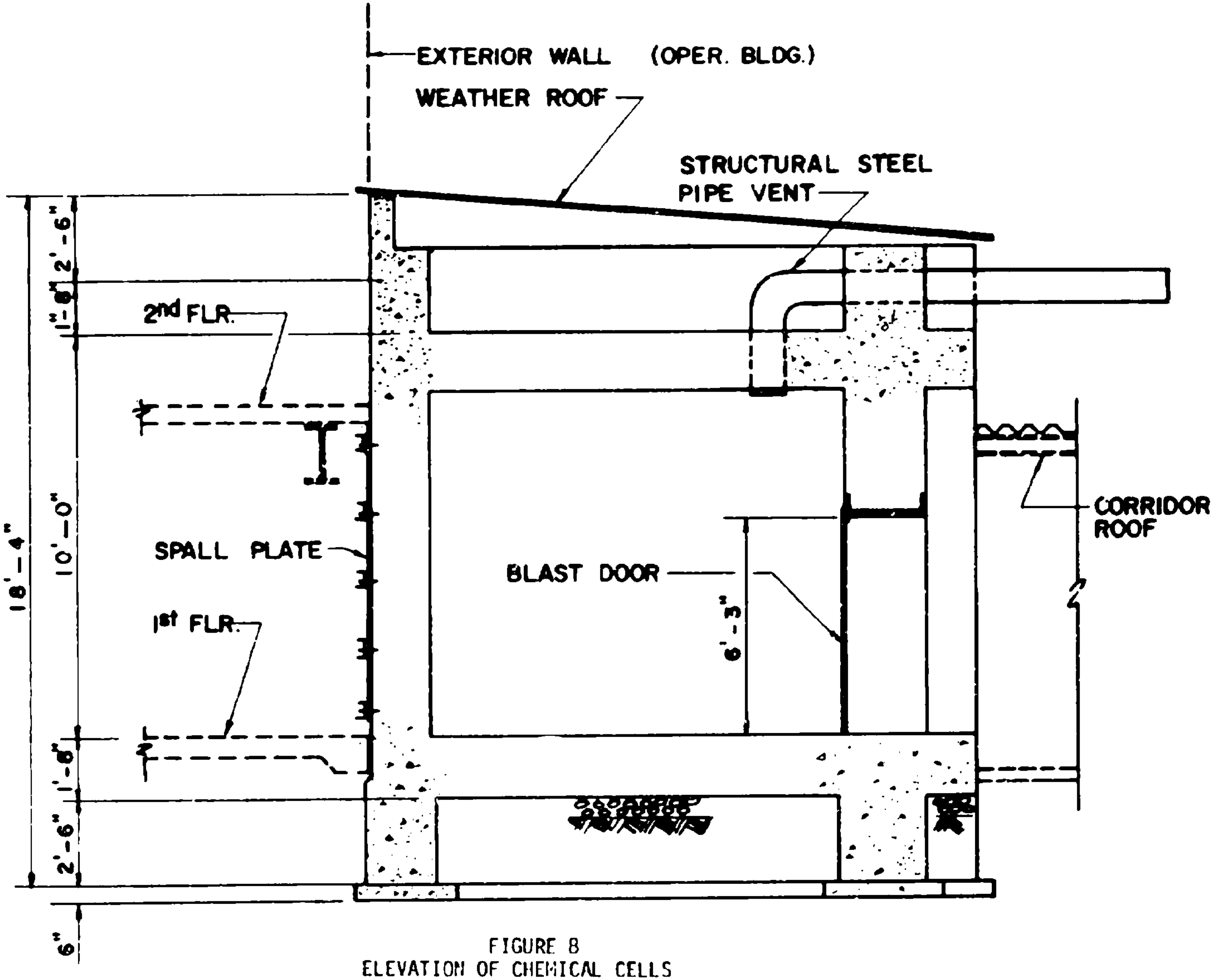


FIGURE 8
ELEVATION OF CHEMICAL CELLS

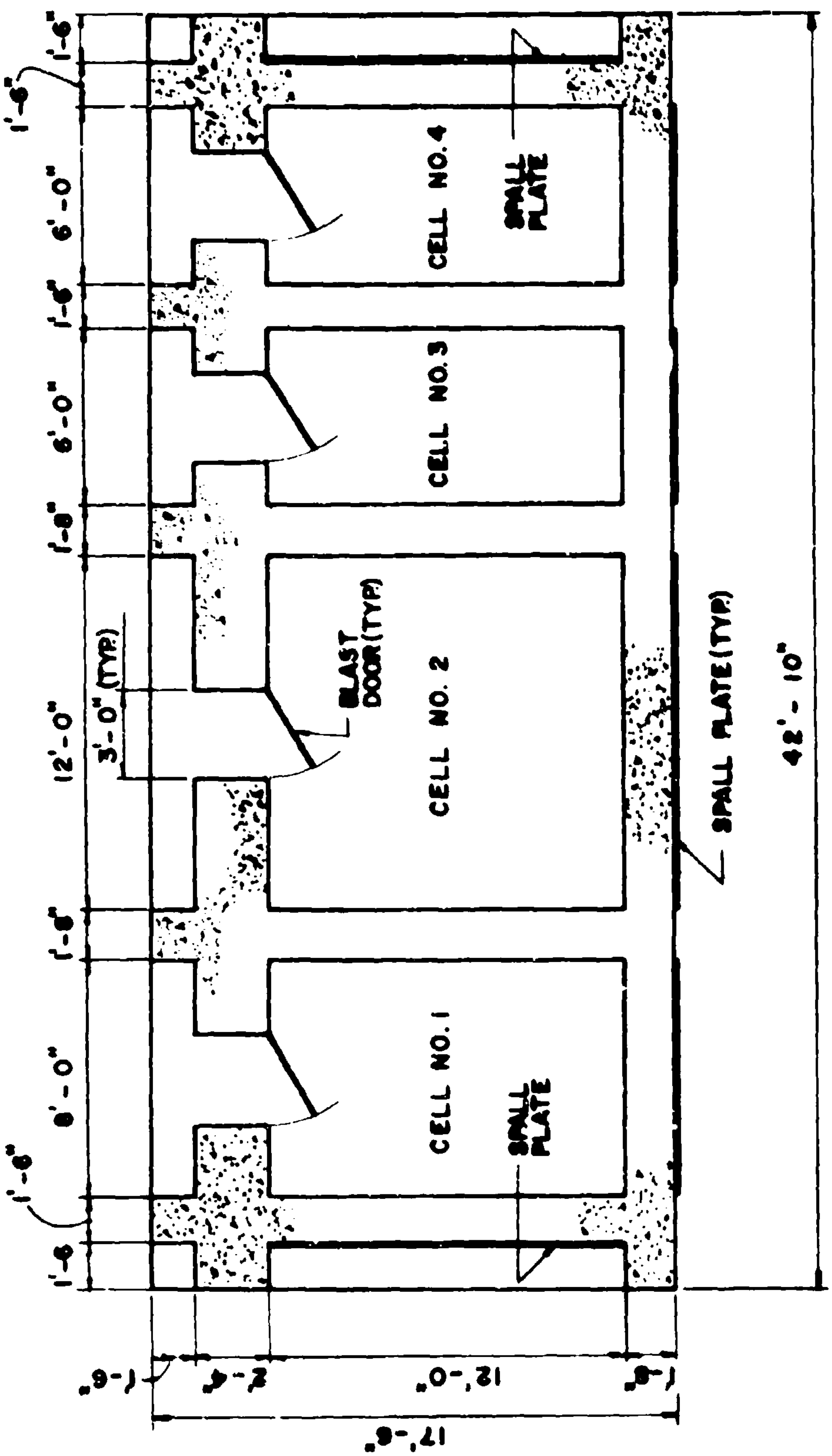


FIGURE 9
PLAN OF CHEMICAL TEST CELLS

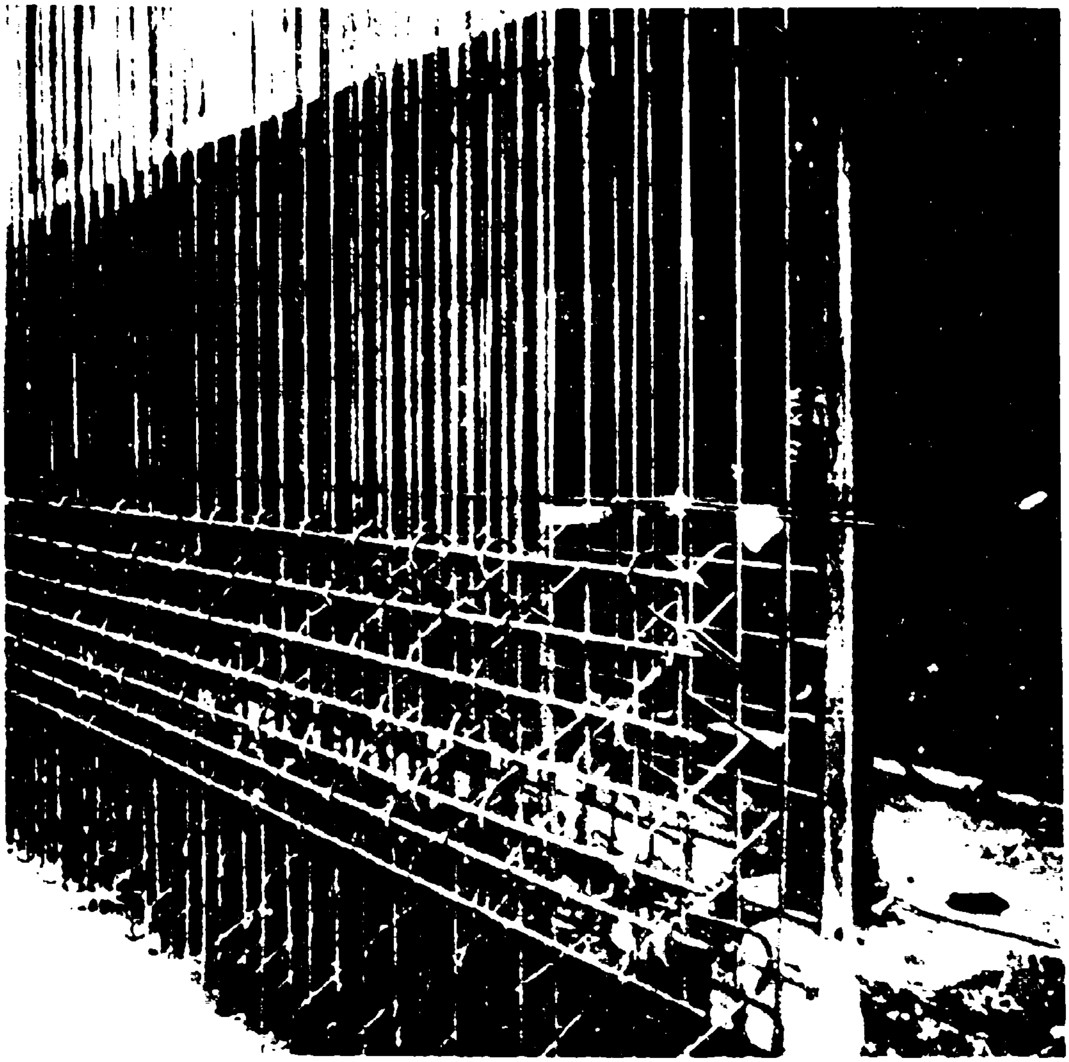


FIGURE 10
TYPICAL REINFORCEMENT LAYOUT

FIGURE 13
FRONT ELEVATION OF PERSONNEL BLAST DOOR

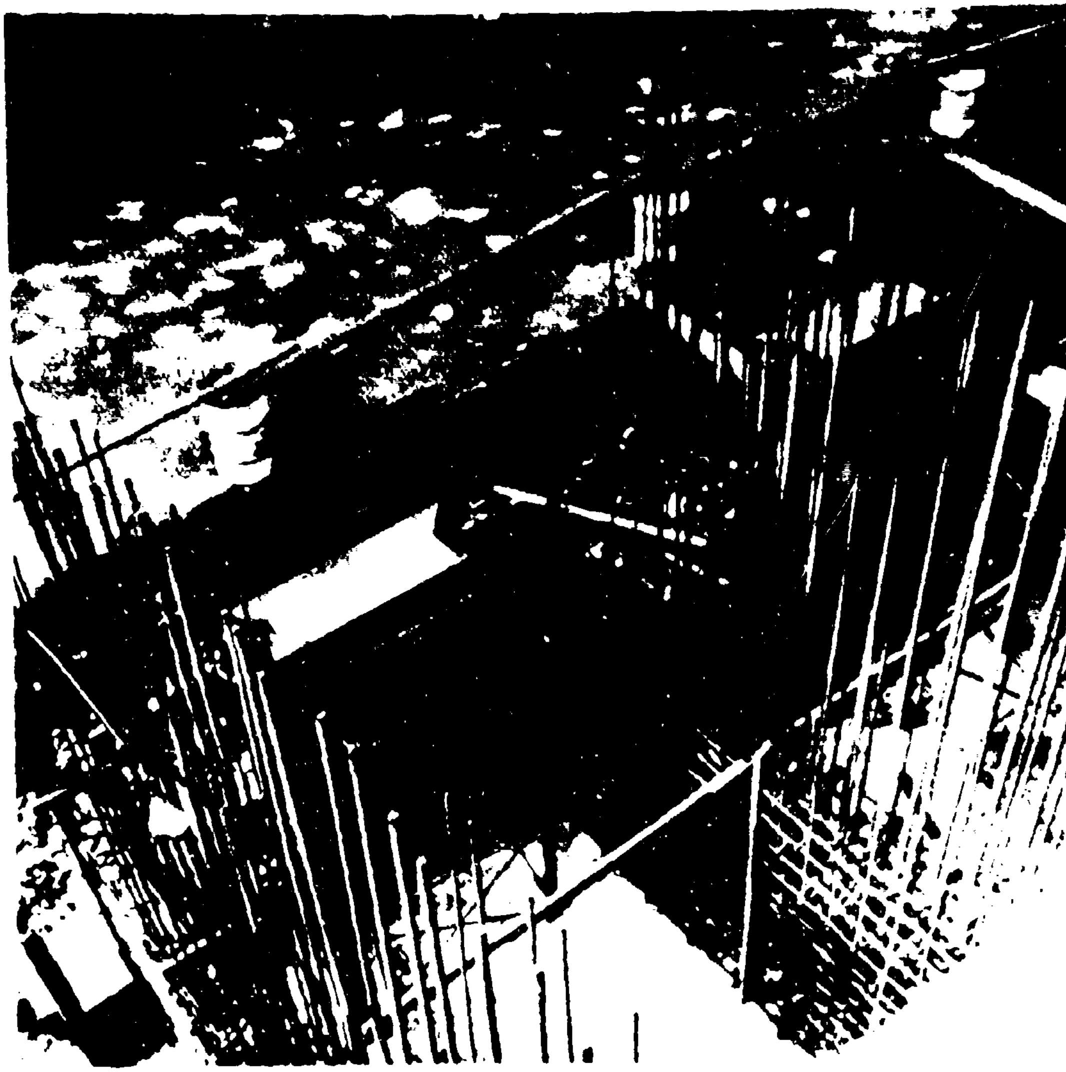


FIGURE 12
REAR ELEVATION OF PERSONNEL BLAST DOOR

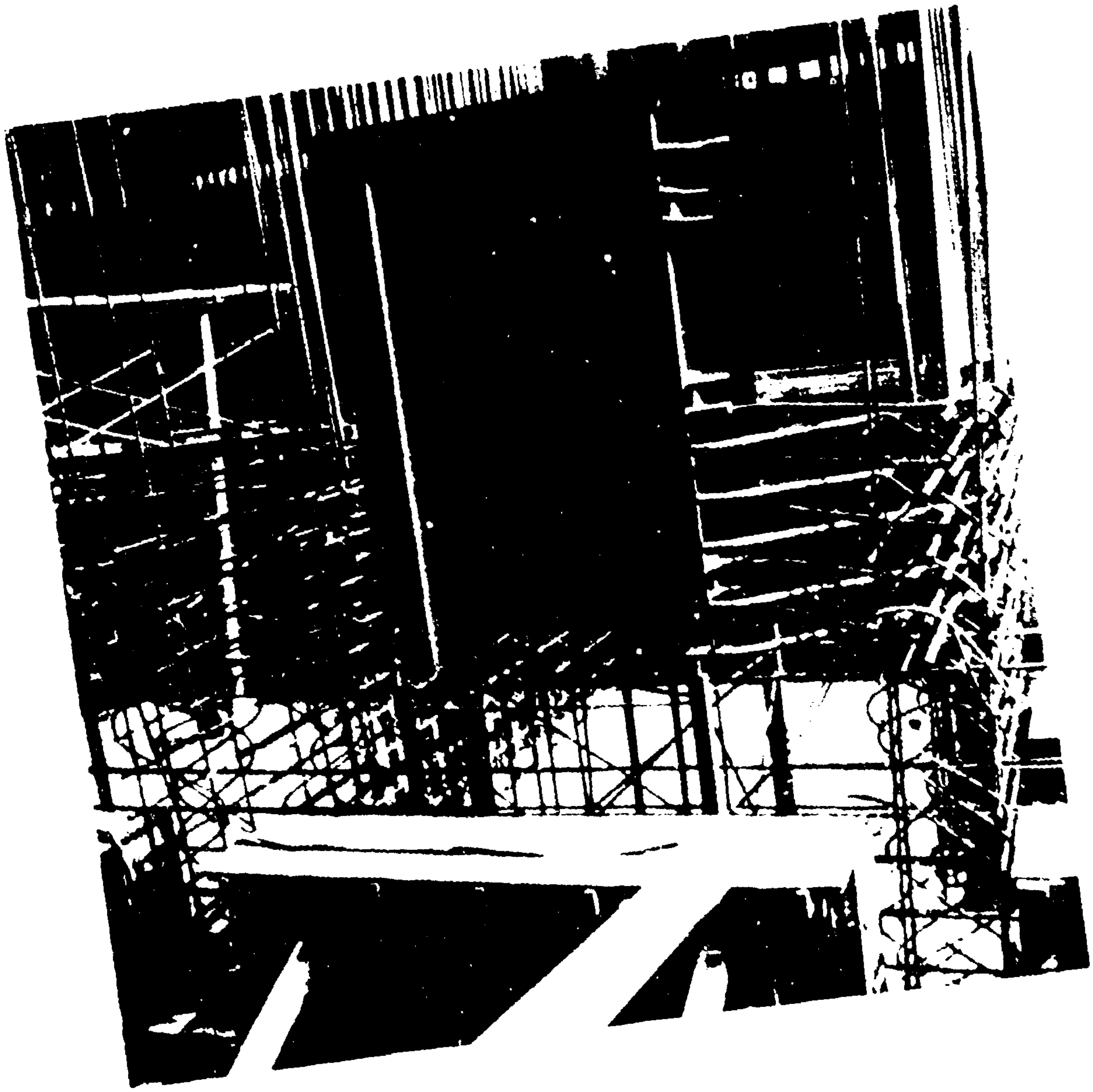
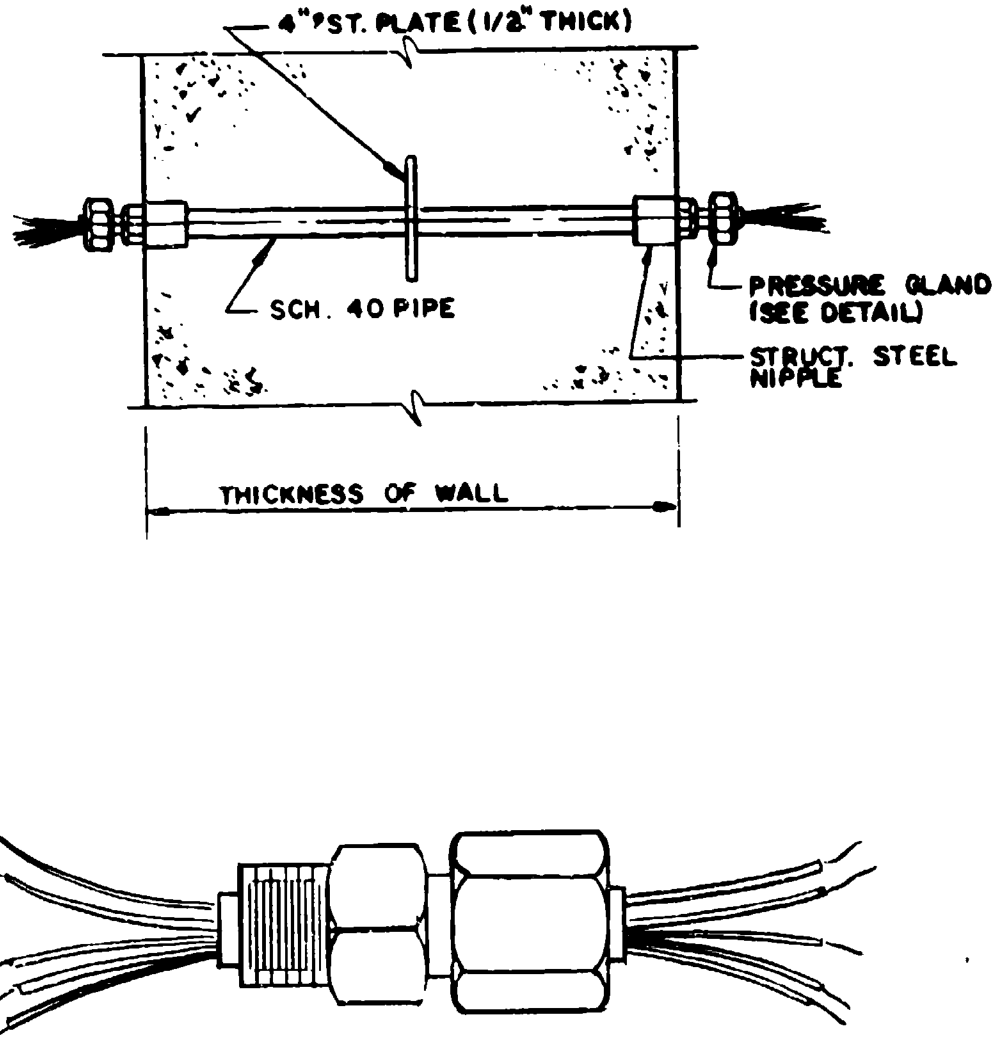


FIGURE 13
REINFORCEMENT CONNECTED TO DOOR FRAME



PRESSURE GLAND DETAIL

Figure 14
Electrical Gland Details

SUSCEPTIBILITY OF ELECTRIC PRIMERS TO ELECTROSTATIC DISCHARGE

Allen F. Schlack
Frankford Arsenal, Phila., Pa.

INTRODUCTION. A significant advance in the primer field was made approximately 25 years ago when normal lead styphnate was first used in the manufacture of priming mixture, thus providing industry with a non-corrosive primer. However, normal lead styphnate has the undesirable characteristic of being highly sensitive to electrostatic discharge. Because of this, a serious safety hazard exists when handling dry normal lead styphnate and dry mixtures containing normal lead styphnate. When priming mixtures with normal lead styphnate as the explosive ingredient are charged into percussion primer components, the resulting primers are safe from electrostatic discharges. However, when these mixtures are charged into electric primer components, the resulting primers can be ignited by electrostatic discharges.

The 20mm, M52A3B1 electric primer has been in production for about 20 years and has proved to perform reliably in the 20mm M55 series of cartridges. This primer contains FA 874 priming composition. A major ingredient of this composition is normal lead styphnate. Figure 1 shows an M52A3B1 primer. It consists of a primer cup, insulated contact button, support cup, and conductive priming mixture. For the primer to function, a capacitive source (160 volts, 2 microfarad capacitor) is connected to a firing pin and the current flows to the contact button, through the conductive mixture to ground. When sufficient energy is applied to the primer, the mixture heats to its ignition temperature and ignites.

Because the 20mm primer is charged with a lead styphnate mixture it can also be ignited by static electricity, which is characterized by high voltage-low capacitance discharge. If stray static charge cause ignition of the primer during handling, serious damage or injury to personnel could result, especially if the primer is assembled in a loaded cartridge.

EXPERIMENTAL RESULTS. In 1970 a limited study was conducted to determine the sensitivity of M52A3B1 primers to electrostatic discharges from an R-C circuit which simulated a human being. Various investigators in the explosive field have used different electrical circuits to simulate humans, as there has been no forceful attempt to create a working group to agree on a standardized circuit. Each investigator uses the circuit which he deems represents a human under the conditions studied. For the subject evaluation the R-C circuit consisted of a 500 picofarad capacitor in series with a 5000 ohm resistor.

Three lots of M52A3B1 primers were evaluated in this study. These primer lots differed only in the resistance level of the primers, which averaged:

Lot A -- 1.5 kilohms

Lot B -- 5 kilohms

Lot C -- 1000 kilohms

Initially, a 50-primer, Bruceton type, voltage/sensitivity test was performed on each lot using a constant voltage pulse of 10 seconds duration. Table I gives the results of these tests. These data indicate that the voltage sensitivity of the primer

increases (i.e., the mean voltage decreases) as the primer resistance decreases.

The sensitivity of each primer lot to electrostatic discharge was then determined electrically, with an R-C circuit connected to each primer. Results of these tests are shown in Table II. With Lot A primers (1.5 kilohms) 10 percent of the primers fired when the capacitor was charged to 5000 volts, while 88 percent of the primers fired when the capacitor was charged to 20,000 volts. With Lot B primers (5 kilohms) 30 percent of the primers fired when the capacitor was charged to 5000 volts while 100 percent of the primers fired when the capacitor was charged to 15,000 volts. With Lot C primers (1000 kilohms) 33 percent of the primers fired when the capacitor was charged to 1000 volts while 100 percent of the primers fired when the capacitor was charged to 10,000 volts.

The data indicate that the susceptibility of the primer to electrostatic discharge increases as the resistance of the primer increases.

The M52A3B1 primer specification states that the resistance of the primer can vary from 1000 to 1,200,000 ohms. It is seen that high resistance primers can be ignited from a low capacitance source at voltages as low as 1000 volts when the primer is electrically connected to the voltage source. Naturally a somewhat higher voltage will be required to initiate the primer in the case of true electrostatic discharges. The magnitude of this voltage will depend on such factors as gap width, humidity and

temperature of the air, shape of electrode, etc. Thus a serious safety hazard may exist during the handling of primers having high resistance.

With this in mind several studies were initiated at Frankford Arsenal to decrease the susceptibility of the primer to electrostatic discharge by modifying the priming composition.

Recently a series of primary explosive compositions consisting of normal lead styphnate containing boron have been prepared which show a marked increase in electrostatic sensitivity over that of normal lead styphnate. It is claimed that these compositions also exhibit increased propellant ignition capability when compared with normal lead styphnate. In order to evaluate the use of lead styphnate/boron compositions in 20mm priming mixtures the four compositions listed in Table III were procured from Canadian Arsenals, Ltd. The boron content of these mixtures increased from 0 to 13 percent.

Four batches of priming mixtures were prepared using the FA 874 formulation but substituting the normal lead styphnate/boron compositions (Table III) for normal lead styphnate, as shown in Table IV. Experimental M52A3B1 primers were assembled with each mixture. The primers were then primed into M103 cases and subjected to voltage sensitivity and primer time tests. The voltage sensitivity tests (Table V) show that as the boron content of the priming mixture increased from 0 to 5.2 percent, the mean critical voltage ($\bar{V}$), the standard deviation of voltage (σ) and the value of $\bar{V} + 3\sigma$ increased. Thus the voltage sensitivity of

the primers decreased with an increase in boron content of the mixtures. The results of the primer time tests (Table VI) show that as the boron content of the mixture increased the average primer time, standard deviation of primer time and the value of average primer time + 4σ increased. Due to deviations in the manufacturing procedure from those designated in the primer drawing, high values of voltage sensitivity and primer time were obtained, and most of the primer lots did not meet the specification requirements. However, the data indicate that primers assembled with the FA 874 formulation containing up to 3.8 percent boron would meet the specified requirements if the proper manufacturing procedure were followed. Primers assembled with FA 874 formulation containing 5.2% boron probably would not meet these requirements without modification of the acetylene black content of the priming composition.

Ballistic data were obtained on 20mm Target Practice, M55 cartridges assembled with WC 846 propellant and each of the five primer lots. All cartridge lots met the specification requirements for velocity, pressure and action time at ambient temperature. Also all the cartridge lots, with the exception of lot BW-4 (5.2% boron in the priming composition), met the action time requirements at -65°F. Two cartridges from lot BW-4 exceeded the 4 ms limit.

Analyses of the results of voltage sensitivity, primer time and ballistic tests indicated that the amount of boron which is to be added to the FA 874 formulation should be less than 5.2% of the mixture.

Electrostatic sensitivity tests were performed on normal lead styphnate/boron compositions in which the boron content increased from 0 to 13.0 percent. For these tests a metal-to-metal approaching electrode method was used. The equipment consisted of a grounded metal bearing containing a sample cavity (3/16 inch diameter by 0.010 inch deep) and a metal electrode connected to a 550 picofarad capacitor. The explosive sample, weighing approximately 0.27 grain (18 mg), was placed on the metal bearing. The electrode was then moved toward the metal bearing and into the explosive material until a spark was obtained, discharging the capacitor. If there was no reaction the above procedure was repeated two times. One of the following was recorded on each sample: (1) complete detonation of sample, (2) partial detonation of sample (where only a small portion of sample detonates cutting a wedge out of the pellet), (3) burn mark in sample (where a small amount of discoloration occurs in sample), or (4) no detonation. Table VII gives the results of the electrostatic sensitivity tests.

The data indicate that as the amount of boron in the normal lead styphnate was increased from 0 to 13 percent, the sensitivity of the explosive composition to electrostatic discharge decreased. As can be seen using an energy of 500 ergs (426 volts) all samples of normal lead styphnate were completely detonated while only three out of ten samples, containing 4.1 percent boron in the lead styphnate, exhibited burn marks. The energy had to be increased

to 2000 ergs (853 volts) before some samples containing 8.6 percent boron in the normal lead styphnate exhibited burn marks. Also, at each energy level, a greater number of reactions were obtained for samples containing 8.6 percent boron in the normal lead styphnate than for the 13 percent sample.

Although no electrostatic sensitivity tests were performed on the experimental mixtures containing lead styphnate/boron compositions, it is believed that the static sensitivity of such mixtures would be proportional to the static sensitivity of the primary explosive used: thus the electrostatic sensitivity would decrease with increasing boron content in the priming mixture.

In another ongoing study, initiating compounds having a lower explosion point and less static sensitivity than normal lead styphnate are being evaluated for use in the FA 874 priming formulation. The following six explosives were synthesized and blended into the priming mixtures listed in Table VIII:

1. Monobasic lead picrate-lead nitrate-lead acetate (Trisal)
2. Basic lead picrate-lead propionate-lead nitrate
3. Basic lead picrate-lead lactate-lead nitrate
4. 2(basic lead picrate-lead azide-lead acetate)-3(lead azide)
5. Dibasic lead picrate-lead nitrate-lead acetate
6. Basic lead picrate-lead nitrate-lead azide

The various mixtures were charged into M52A3B1 components. After measuring the primer resistances, the primers were subjected

to voltage sensitivity tests using a 2 microfarad capacitor. The results of these tests are given in Table IX. The resistance levels of the primers charged with mixtures XP 521, XP 523, XP 524 and XP 528 thru XP 531 were within the specification requirement of 1000 to 1,200,000 ohms, while the resistance levels of all other primer lots were below the requirement (with the exception of that lot charged with XP 520). Some primers from this latter lot exhibited extremely high resistances.

The mean critical voltage ($\bar{V}$) of the primer lots charged with mixtures XP 522, XP 525 thru XP 527 and XP 529 thru XP 531 were satisfactory, while the $\bar{V}$ of all other primer lots were higher than desired. Although the primers charged with the azide mixtures (XP 525, XP 526, XP 527 and XP 531) exhibited satisfactory sensitivity, in general their resistances were low, and their explosive outputs were violent.

The data indicate that the substitution of Trisal for normal lead styphnate in the FA 874 priming mixture (XP 529) produced the best results.

Table X shows electrostatic sensitivity data on the initiating compounds evaluated in this study. It can be seen from this table that the initiating compounds are considerably less static sensitive than normal lead styphnate. All the normal lead styphnate test samples were detonated using only 500 ergs of energy whereas the other initiating compounds required at least 6000 ergs to detonate one hundred percent of the test samples.

From the previous work it is of note that a safety hazard may exist due to electrostatic discharges when handling M52A3B1 primers whose average resistance approaches one million ohms. This previous work also indicated that substitution of either 1) lead styphnate/boron compositions with 8 percent boron or 2) Trisal for n-lead styphnate in the FA 874 formulation decreases the susceptibility of these primers to electrostatic discharges.

FUTURE EFFORT. To complete the development of a 20mm primer containing the new explosive compositions discussed here, and to perform adequate testing to qualify them for use in the various 20mm cartridges is costly. Before allocating large sums of money to qualify a new primer, it is our desire to determine the extent of the electrostatic hazard and to determine whether these new compositions can provide adequate protection to this hazard.

With this in mind, a contract effort is being placed by Frankford Arsenal to determine the susceptibility of the M52A3B1 primer to electrostatic discharges from a human subject. Four studies are to be conducted using the following environmental conditions: +40°F (30 percent relative humidity); 0°F (no humidity requirement); and -40°F (no humidity requirement). For informational purposes the humidity is only to be measured and recorded at temperatures of 0° and -40°F. For those studies in which a human subject is used, the subject is to be dressed in typical Army uniform for each environmental condition evaluated. Initially the capacitances and resistances of the subjects to be

used in these studies is to be determined for each environmental condition.

The four studies to be conducted under this future effort are as follows:

Study 1. Determination of the amount of stored charge on a human subject which can be effectively delivered to a primer simulator. In this study the resistance level of the simulator will be varied from 30,000 ohms to 1,000,000 ohms while the charge on the subject will be varied from 500 to 6000 volts. The data collected canbe plotted to obtain curves similar to those shown in Figure 2.

Study 2. Determination of the amount of stored charge on a capacitor which can be effectively delivered to a primer simulator. Again in this study the resistance level of the simulator will be varied from 30,000 to 1,000,000 ohms while the charge on the capacitor will be varied from 500 to 6000 volts. The data collected can be plotted to obtain curves similar to those shown in Figure 3.

Study 3. Determination of $\bar{V}$ and the threshold voltage required to ignite a cased M52A3B1 primer. In this study, three lots of M52A3B1 primers assembled in M103 cases will be evaluated. These lots of primers will differ only in resistance level as follows: Lot ES-1 , 10,000 to 50,000 ohms; Lot ES-2, 100,000 to 500,000 ohms and Lot ES-3, 800,000 to 1,200,000 ohms. The energy delivered to the primer at the $\bar{V}$ and threshold voltages is to be measured in this study.

Study 4. Determination of the amount of stored charge on a human subject which can be delivered to a primer simulator under simulated field conditions. This study will be performed by having the charged subject stand on an insulated platform and approach the primer simulator such that the subject's finger, mitten or any implement carried by subject is extended so as to touch the simulator. The subject will be charged to the following voltages: 1) $\bar{V}$, 2) $\bar{V} + 3\sigma$ and 3) that voltage where 100 percent of the primers can reasonably be expected to fire if the subject is electrically connected to the primer. The resistance level of the simulator will be varied from 30,000 to 1,000,000 ohms.

From the data obtained in these four studies, the probability of ignition of the M52A3B1 primer from a human subject, when the subject is charged to voltages varying from 800 to 4000 volts, is to be estimated.

In order to determine the extent of the electrostatic hazard from personnel working with and around 20mm ammunition, data also must be gathered concerning the charge which can be generated by these personnel under the environmental conditions studied. Some studies have been performed by U.S. Army Natick Laboratories and the Aerospace Medical Division, Air Force Systems Command, to determine the accumulation of static electricity on Arctic clothing. These tests indicated that the voltage accumulated on various items of clothing worn by test personnel ranged from 100 to 1400 volts. These data are limited and were obtained under specific working conditions. Therefore, the results may

bear little relationship to results obtained on personnel handling ammunition for the XM35 system, for which our work is being conducted.

Initially the results obtained in the above studies will be used to assess the extent of the electrostatic hazard in handling 20mm ammunition. If there is a high probability that the primer can be ignited by test personnel, a recommendation will be made to determine the static charge which can be accumulated on the clothing of personnel working with the XM35 system.

This ongoing investigation is being conducted under the Army's Product Improvement Program. Results of this effort will be made available to qualified requestors in the form of a Frankford Arsenal Technical Report.

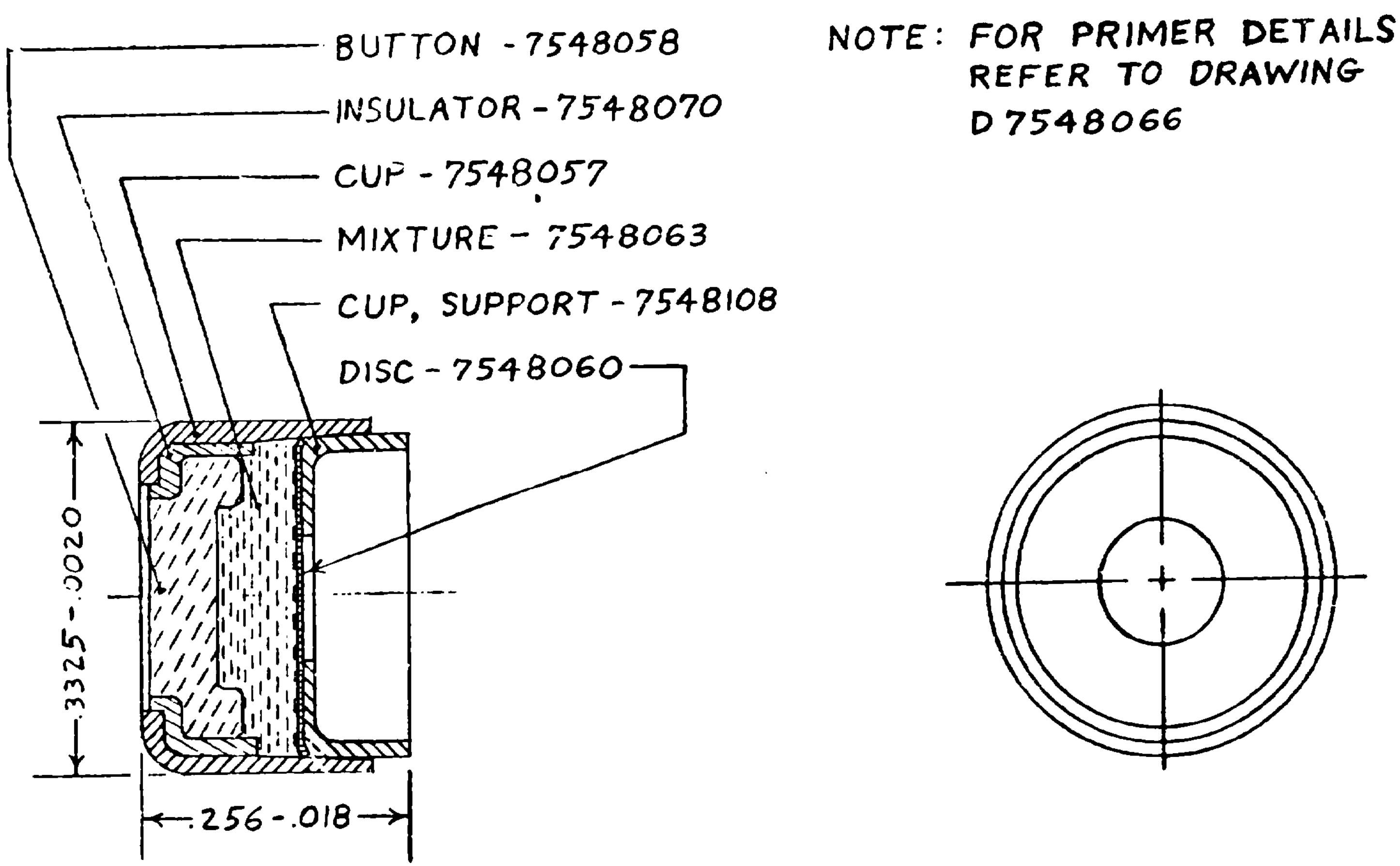


Figure 1 Primer, Electric, M52A3B1, Assembly

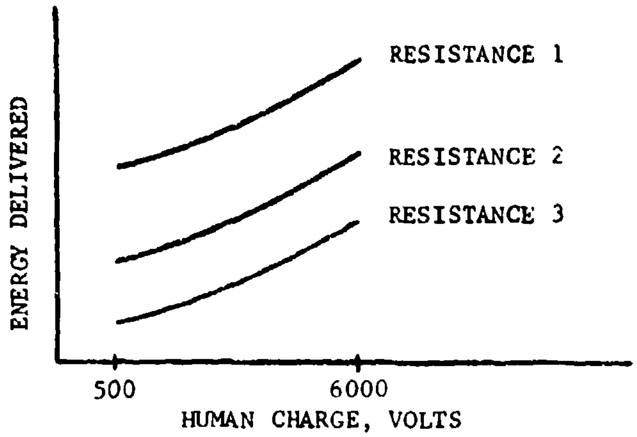


FIGURE 2. RELATIONSHIP BETWEEN ENERGY DELIVERED TO PRIMER SIMULATOR AND CHARGE ON HUMAN SUBJECT AT +40°F, 30% RELATIVE HUMIDITY.

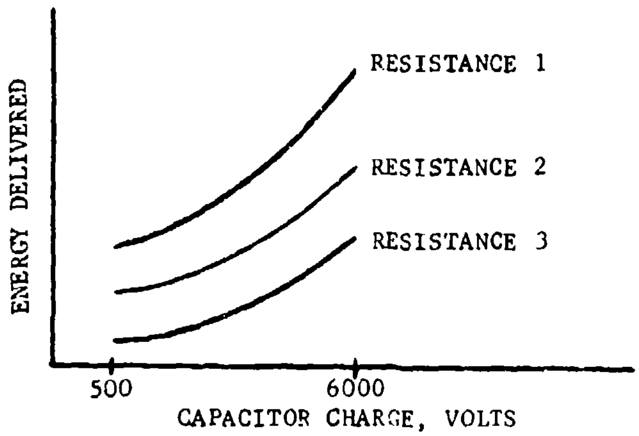


FIGURE 3. RELATIONSHIP BETWEEN ENERGY DELIVERED TO PRIMER SIMULATOR AND CHARGE ON CAPACITOR

TABLE I. RESULTS OF 50 PRIMER BRUCETON VOLTAGE SENSITIVITY TEST

LOT IDENTIFICATION	AVERAGE RESISTANCE (KILOHMS)	MEAN FIRING LEVEL (VOLTS)
A	1.5	16.8
B	5	20.4
C	1000	49.5

TABLE II. RESULTS OF ELECTROSTATIC SENSITIVITY TESTS

AVERAGE PRIMER RESISTANCE (KILOHMS)		VOLTAGE LEVEL (KILOVOLTS) 1.0	1.5	2.0	2.5	5.0	10.0	15.0	20.0
1.5	NO. PRIMERS TESTED					10	9	10	9
	PERCENT FIRING					10	44	60	88
5	NO. PRIMERS TESTED					10	7	9	5
	PERCENT FIRING					30	43	100	100
1000	NO. PRIMERS TESTED	12	6	14	3	8	6		
	PERCENT FIRING	33	33	43	66	100	100		

NOTE: ENERGIZING R-C CIRCUIT CONSISTED OF A 500 PICOFARAD CAPACITOR IN SERIES WITH A 500 OHM RESISTOR.

TABLE III. CHEMICAL ANALYSES OF LEAD STYPHNATE/BORON COMPOSITIONS PURCHASED FROM CANADIAN ARSENALS, LTD.

BATCH NO.	BULK DENSITY (GRAMS/CC)	PERCENT BORON	PERCENT LEAD	ASSAY*
7	1.16	0	43.7	98.8
9	0.99	4.86	42.1	94.0
11	0.93	9.60	40.7	89.1
13	0.86	12.9	38.7	85.4

* AS LEAD STYPHNATE FROM STYPHNATE RADICAL

TABLE IV. FORMULATIONS OF MIXTURES EVALUATED IN THIS STUDY

INGREDIENTS	PERCENT COMPOSITION BY WEIGHT			
LOT NUMBER	BW-1	BW-2	BW-3	BW-4
N-LEAD STYPHNATE	40.0	38.1	36.2	34.8
BORON	0.0	1.9	3.8	5.2
CALCIUM SILICIDE	13.0	13.0	13.0	13.0
BARIUM NITRATE	44.2	44.2	44.2	44.2
ACETYLENE BLACK	0.8	0.8	0.8	0.8
GUM ARABIC	1.0	1.0	1.0	1.0
2, 4, 6 TRINITRORESORCINOL	1.0	1.0	1.0	1.0
BORON CONTENT OF LEAD STYPHNATE	0.0	4.86	9.60	12.9

TABLE V. RESULTS OF VOLTAGE SENSITIVITY TESTS* ON PRIMERS CONTAINING LEAD STYPHNATE/BORON COMPOSITIONS IN THE MIXTURES

LOT NO.	% BORON	$\bar{V}$ (VOLTS)	σ_V (VOLTS)	$\bar{V} + 3\sigma_V$ (VOLTS)***
BW-1	0	63.2	19.0	120.2
BW-2	1.9	84.4	21.6	149.2
BW-3	3.8	98.4	22.4	165.6
BW-4	5.2	126.0	31.0	219.0
LC-SP-1377**	0	42.6	8.4	67.8

* 50 PRIMERS TESTED PER VOLTAGE INCREMENT, USING A 4 MICROFARAD CAPACITOR WITH CONTINUOUS PULSE

** CONTROL LOT - 2 MICROFARAD CAPACITOR WITH 10 MICROSECOND PULSE

*** REQUIREMENT - $\bar{V} + 3\sigma$ <160 VOLTS WHEN PRIMER IS ENERGIZED BY 10 MICROSECOND DISCHARGE FROM A 2 MICROFARAD CAPACITOR

TABLE VI. RESULTS OF PRIMER TIME TESTS* ON PRIMERS CONTAINING LEAD STYPHNATE/BORON COMPOSITIONS

LOT NO.	% BORON	AVERAGE PRIMER TIME(t_{AVE}) (μSEC)	STD DEV(σ_t) (μSEC)	($t_{AVE} + 4\sigma_t$)**** (μSEC)
BW-1	0	105.7	14.6	164.1
BW-2	1.9	119.4	24.9	219.0
BW 3	3.8	138.6	26.6	245.0
BW-4	5.2	252.9	131.2	777.7
SC-SP-1377**	0	72.2	6.1	96.6
LC-SP-1377***	0	92.7	19.4	170.3

* 50 PRIMERS TESTED PER LOT, USING 4 MICROFARAD CAPACITOR, 200 VOLTS, CONTINUOUS PULSE

** CONTROL LOT

*** CONTROL LOT TESTED WITH 2 MICROFARAD CAPACITOR CHARGED TO 160 VOLTS WITH 10 MICROSECOND PULSE

**** REQUIREMENT -- $t_{AVE} + 4\sigma_t < 300$ μSEC, WHEN PRIMER IS ENERGIZED BY 10 MICROSECOND DISCHARGE FROM A 2 MICROFARAD CAPACITOR CHARGED TO 160 VOLTS.

TABLE VII. RESULTS OF ELECTROSTATIC SENSITIVITY TESTS* ON LEAD STYPHNATE/BORON COMPOSITIONS

VOLTAGE (VOLTS)	ENERGY (ERGS)	BATCH NUMBER 6	8	10	12
		NO. SAMPLES TESTED/NO. DETONATIONS			
191	100	50/1	----	----	----
330	350	22/14	----	----	----
381	400	10/7	----	----	----
405	450	15/9	----	----	----
426	500	10/10	10/3B	----	----
603	1000	----	10/6B	20/0	----
853	2000	----	10/10B	20/2B	20/1P
1045	3000	----	----	20/2P,5B	20/1P,1B
7385	150000	----	----	----	4/4P
10450	300000	----	----	----	1/1
PERCENT BORON IN STYPHNATE		0.0	4.13	8.60	13.0

NOTE: B -- BURN MARK INDICATES DISCOLORED SAMPLE
P -- PARTIAL DETONATION OF SAMPLE

* TEST DETERMINED BY CANADIAN ARSENALS, LTD. SAMPLE SIZE - 18 MG. CAPACITOR -- 550 PICOFARADS

TABLE VIII. COMPOSITION OF PRIMING MIXTURES

LOT NUMBER	EXPLOSIVE	BARIUM NITRATE	CALCIUM* SILICIDE	ACETYLENE BLACK	GUM ARABIC
XP 520	40A	45	12.5	0.85	1.0
XP 521	40A	45	12.5	0.95	1.0
XP 522	40A	45	12.5	1.5	1.0
XP 523	40B	45	12.5	1.5	1.0
XP 524	40C	45	12.5	1.5	1.0
XP 525	40D	45	12.5	1.5	1.0
XP 526	30D	55	12.5	0.85	1.0
XP 527	30D	55	12.5	1.0	1.0
XP 528	40E	45	12.5	1.5	1.0
XP 529	40A	45	12.5	1.25	1.0
XP 530	40F	45	12.5	1.25	1.0
XP 531	40G	45	12.5	1.25	1.0

A -- MONOBASIC LEAD PICRATE/LEAD NITRATE/LEAD ACETATE (TRISAL)
B -- BASIC LEAD PICRATE/LEAD PROPIONATE/LEAD NITRATE
C -- BASIC LEAD PICRATE/LEAD LACTATE/LEAD NITRATE
D -- 2(BASIC LEAD PICRATE/LEAD AZIDE/LEAD ACETATE), 3(LEAD AZIDE)
E -- 30 PARTS TRISAL, 10 PARTS TETRACENE
F -- DIBASIC LEAD PICRATE/LEAD NITRATE/LEAD ACETATE
G -- BASIC LEAD PICRATE/LEAD NITRATE/LEAD AZIDE

* TREATED WITH TNR

TABLE IX. RESULTS OF VOLTAGE SENSITIVITY TESTS* ON PRIMERS CONTAINING NEW EXPLOSIVES IN FA 874 MIXTURE

MIXTURE NUMBER	RESISTANCE LEVEL (KILOHMS)	$\bar{V}$ (VOLTS)
XP 520	250 to ∞	140
XP 521	100 to 300	123**
XP 521	300 to 1000	133
XP 522	0.99	80**
XP 523	67.9	147
XP 524	132	182
XP 525	0.07	37
XP 526	0.43	80
XP 527	0.23	77
XP 528	31.8	195
XP 529	9.5	88
XP 530	1.4	100
XP 531	4.3	80

* 25 PRIMER BRUCETON TEST PERFORMED USING 2 MICROFARAD CAPACITOR WITH CONTINUOUS PULSE

** COMPLETE RUNDOWN TEST PERFORMED, TESTING 25 PRIMERS PER VOLTAGE INCREMENT, USING 2 MICROFARAD CAPACITOR WITH CONTINUOUS PULSE

TABLE X. ELECTROSTATIC SENSITIVITY OF INITIATING COMPOUNDS

INITIATING COMPOUND	VOLTAGE (VOLTS)	ENERGY** (ERGS)	PERCENT FIRED
MONOBASIC LEAD PICRATE/LEAD NITRATE/LEAD ACETATE (TRISAL)	6000	54,000	0
BASIC LEAD PICRATE/LEAD PROPIONATE/LEAD NITRATE	3000*	13,500	100
BASIC LEAD PICRATE/LEAD LACTATE/LEAD NITRATE	2000*	6,000	100
2(BASIC LEAD PICRATE/LEAD AZIDE/LEAD ACETATE)-3(LEAD AZIDE)	---	---	---
DIBASIC LEAD PICRATE/LEAD NITRATE/LEAD ACETATE	4000	24,000	0
BASIC LEAD PICRATE/LEAD NITRATE/LEAD AZIDE	4000	24,000	0
NORMAL LEAD STYPHNATE	426*	500***	100

* MINIMUM VOLTAGE REQUIRED TO FIRE 100 PERCENT OF THE TEST SAMPLES.

** 300 PICOFARAD CAPACITOR WAS USED.

*** 550 PICOFARAD CAPACITOR WAS USED.

THE ADDITION OF [illegible] SAFETY CHARACTERISTIC INTO AN INHERENTLY SAFE ELECTRIC [illegible] INITIATOR

[illegible]
Reynolds Industries [illegible], Calif.

I. INTRODUCTION

The exploding bridgewire (EBW) detonator as shown in Fig. [illegible] is an electric explosive initiator which contains only secondary explosives such as PETN or RDX for both the initiating charge next to the bridgewire and the output charge. (Reference 1) The most common electric initiators use a heat sensitive primary explosive such as lead azide or lead styphnate next to the bridgewire to start the detonation. These low energy initiators require only a heating of the bridgewire for detonation. An EBW detonator, which is generally referred to as a high energy detonator, requires a high energy shock wave from the bridgewire for proper detonation due to the secondary explosive next to the wire. (Reference 2) This feature gives an EBW detonator a significant safety advantage over a low energy detonator from an accidental detonation standpoint.

To properly function an EBW detonator, the bridgewire must be subjected to a very fast, high energy pulse such as that shown in Figure 2. This pulse must consist of several hundred amperes of peak current supplied within a microsecond to the bridgewire.

It is possible to cause a secondary explosive to burn by heating it to its ignition temperature. This burning of a secondary explosive is non-violent, providing the explosive is not confined. If it is confined, as is the case with most explosive initiators, the reaction of a burning secondary explosive will not reach that of a detonation, but if not vented, it can be relatively violent. An example of such an EBW detonator is shown in Figure 3. This EBW

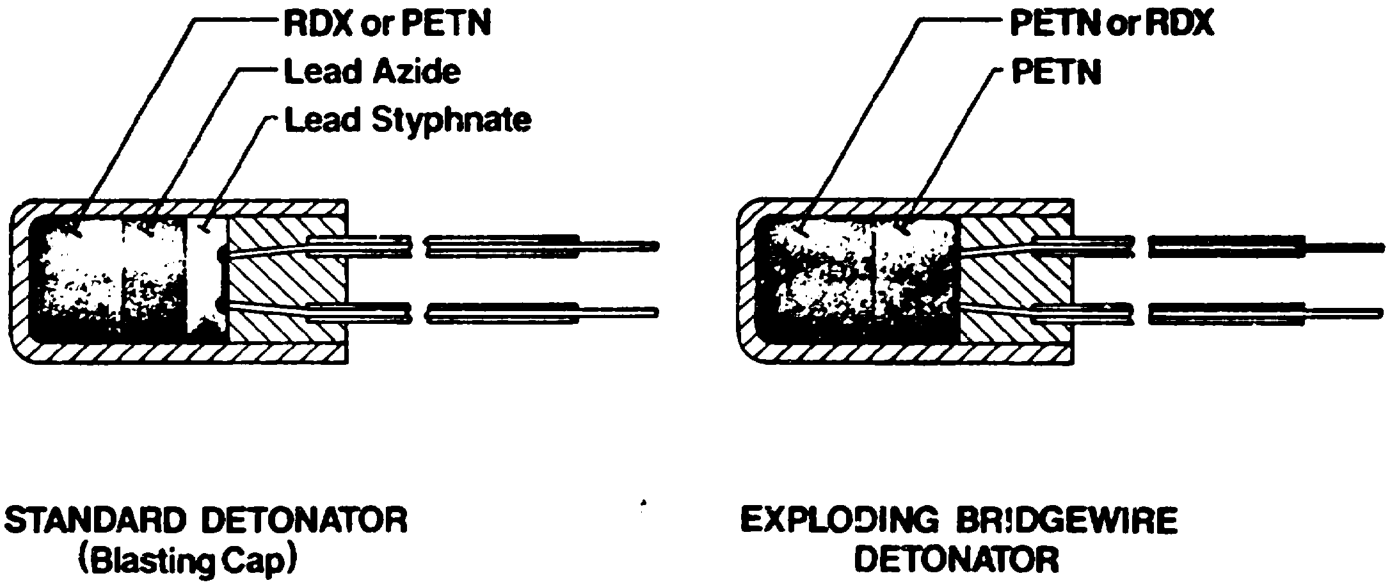


FIGURE 1
DETONATOR COMPARISON

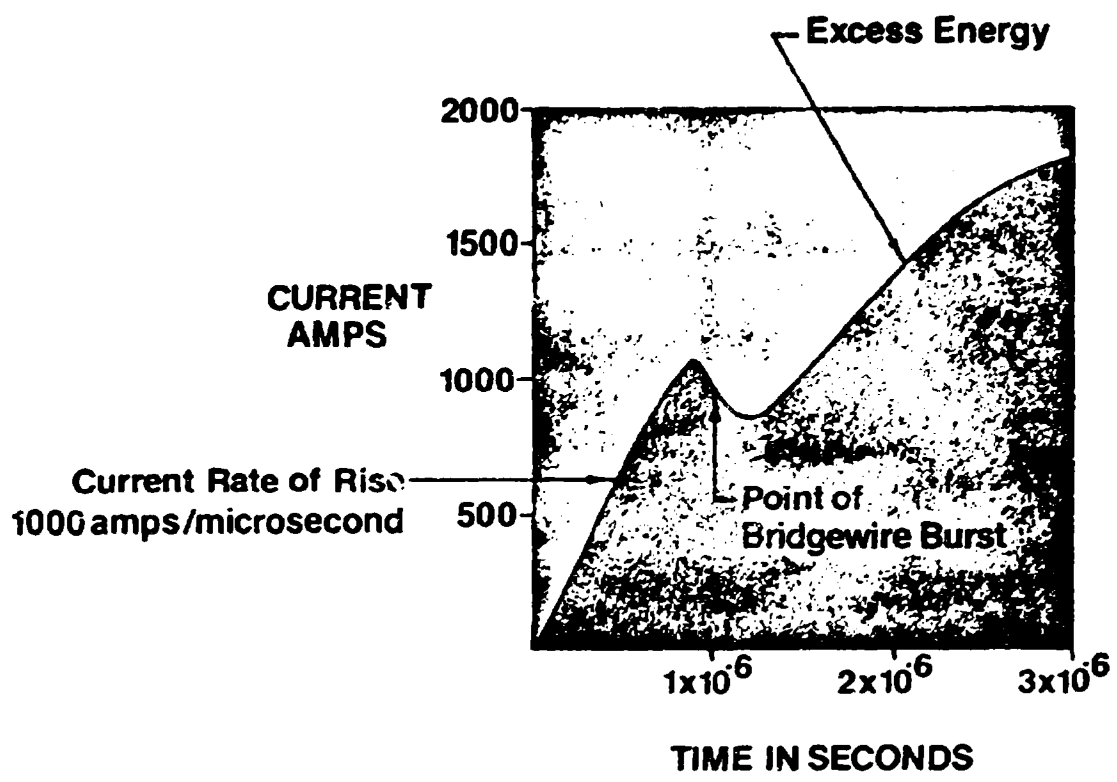


FIGURE 2
Exploding Bridgewire Current Trace

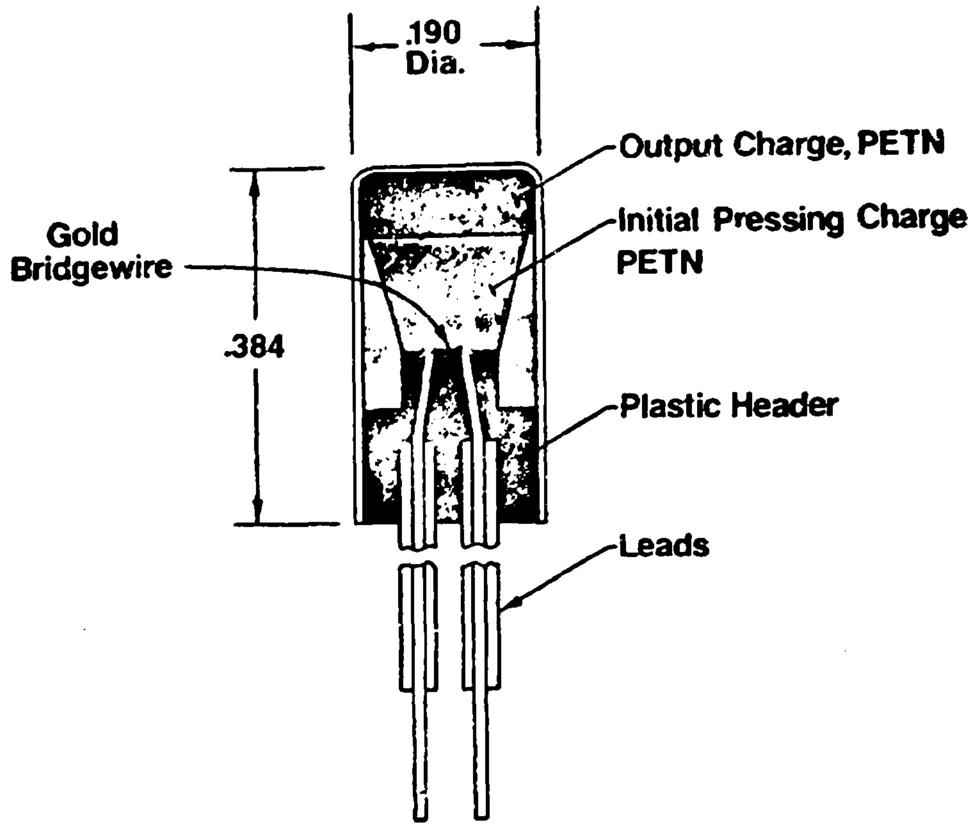


FIGURE 3
RP87 DETONATOR
CONSTRUCTION

detonator duplicates the geometry and output of the Navy's Mark 87 electric detonator, which is a low energy, highly sensitive detonator. The detonator shown here, however, has an explosive charge containing only secondary explosive. This detonator consists of a header, an initial pressing of PETN next to the bridgewire, an output charge of PETN and a steel cup which is pressed onto the plastic head and rolled over for containment and sealing.

The results of a normal detonation of this detonator are shown in Figure 4. A dent in excess of .014 inch is obtained in a steel

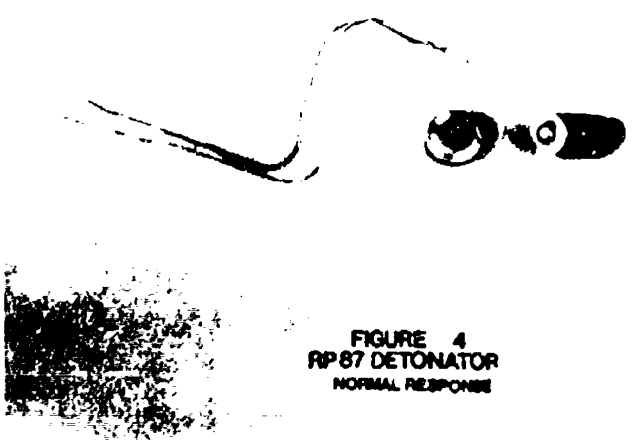


FIGURE 4
RP 87 DETONATOR
NORMAL RESPONSE

block. A brass sleeve, if used, is significantly expanded and the header and other metal parts are completely destroyed.

A burning or deflagration response is shown in Figure 5. The important factor to note is that this deflagration does not cause

a dent in the steel block and therefore this type of response would not transfer detonation to the next charge. However, this response does blow apart the detonator with a relatively violent action which could cause possible injury to a person holding the detonator. This type of response is difficult to obtain since it requires, in general, more continuous energy than is required to perform a normal firing. However, these types of energy quantities are available from a standard 110 volt alternating current wall socket. In tests, we obtained approximately 90% deflagration responses from 110 volt A.C. current input. The remaining 10% of the detonators tested resulted in no explosive response. In these detonators the bridgewire would

break and open the circuit before a significant amount of current is allowed to pass through the detonator. Since explosive accidents have occured due to accidental hookup, grounding, shorting, or whatever, to a 110 volt A.C. energy, it was felt that a detonator which would not respond under any direct contact with a wall socket would be desirable.

Since an EBW detonator is inherently safe because it contains only secondary explosives, there is a great deal of flexibility that can be accomplished to change its characteristics as required for some particular need. This report describes a relatively straight forward solution to enable any EBW detonator to be plugged into 110 volt A.C. circuit and not have any explosive response.

II. SAFETY CHARACTERISTIC CONCEPT

There are several possible approaches to eliminating this deflagration of an EBW detonator due to a 110 volt A.C. energy source. Figure 6 dipicts four possible design concepts. The first concept consists of putting a spark gap in series with the bridge-wire. This gap can be designed to break down in excess of the 110, 220, or 440 A.C. peak voltage levels so that no current will pass through unless a higher voltage is reached such as the actual firing pulse. The disadvantages of this design is that a reliable spark gap must be hermetically sealed, which results in a high cost and significantly larger detonator.

A second approach is to add a vent into the explosive cavity near the bridgewire. With this design, gas pressure due to a deflagration is pressure dependent, it will terminate. The disadvantages of this concept are that in many assemblies the vent hole would be sealed and therefore would not properly vent. Also, to

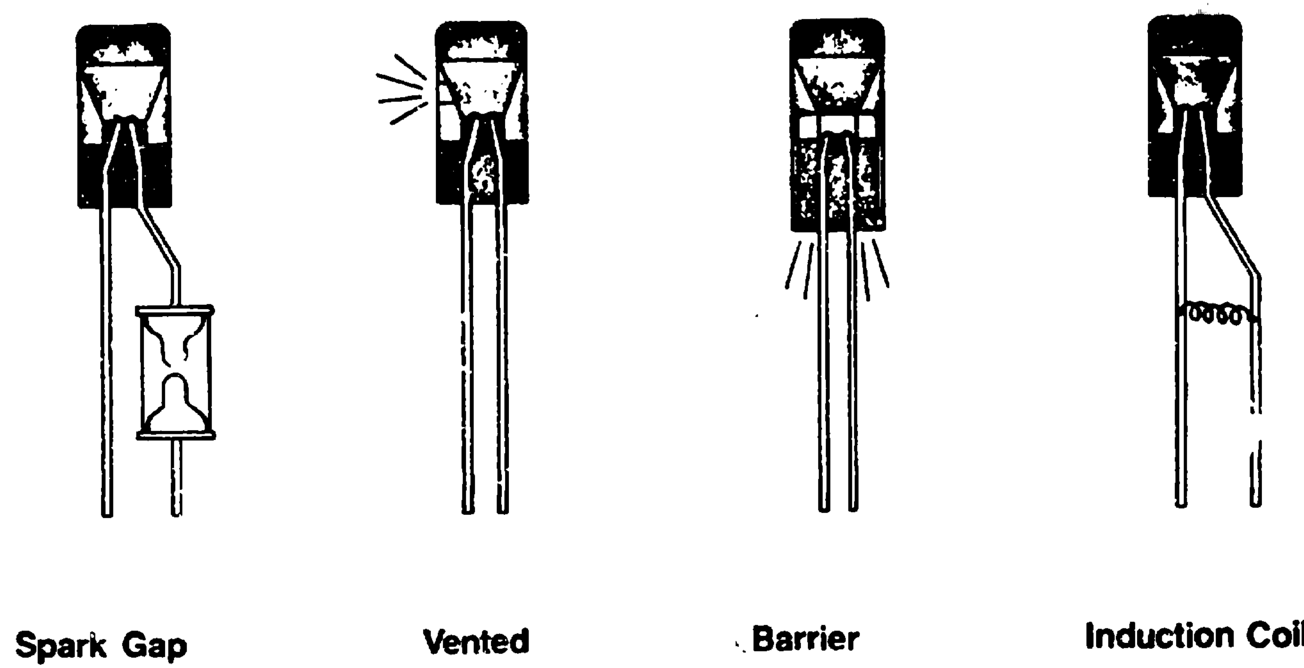


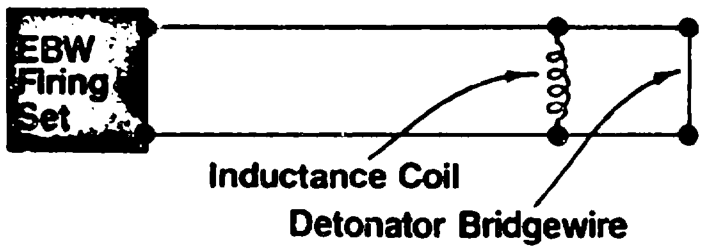
FIGURE 6
EBW DETONATOR
110VAC/Protection Concepts

properly terminate a deflagration, it was determined that venting must occur at very low pressures which presents an environmental seal problem to the overall detonator design.

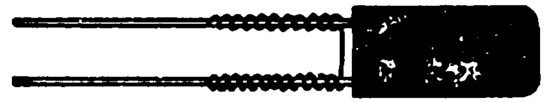
The third approach was to place a barrier between a small initial pressing of PETN explosive next to the bridgewire and the main charge in the detonator. The shock wave from a proper detonation of this small initial pressing charge would pass through the barrier and detonate the output. However, a deflagration of the small initial pressing would not pass through the barrier. This concept worked except it was found that even the small initial pressing charge, which we decreased down to 4 milligrams of PETN, required venting such as pushing the header out the back end of the detonator. Also, it was found that the walls of the cup had to be substantially increased in thickness to allow the header to vent pri r to fracturing the cup.

The fourth design approach appeared to have the most promise from the standpoint of (1) cost, (2) minimum added volume and (3) no venting required. This concept consists of placing a small induction coil into the detonator circuit in parallel with the bridgewire.

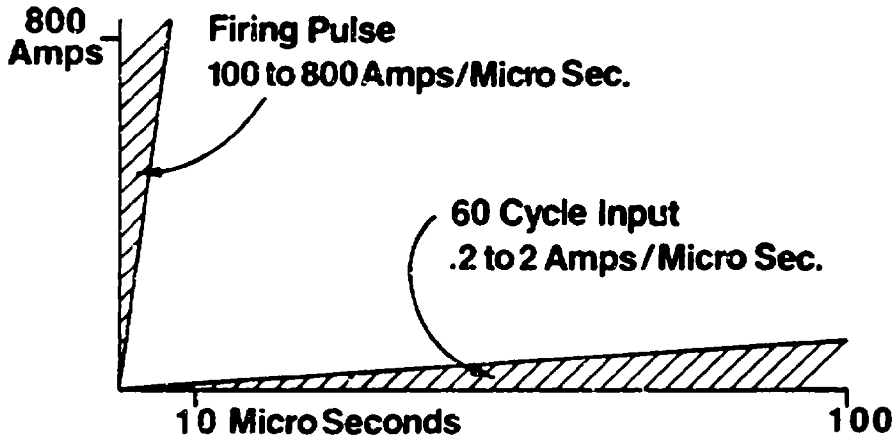
Figure 7 depicts this design concept. Proper functioning of an EBW detonator is dependent upon the rise time of the firing pulse to obtain the proper shockwave and energy density from the bridgewire. In general, this firing current must be applied at a rate of 100 to 1,000 amps per microsecond. The current rise time from 60 cycle A.C. current using standard mechanical switching methods is less than 2 amps per microsecond. By placing an inductance coil in parallel with the



CIRCUIT



POSSIBLE CONFIGURATION



Pulse Comparison

FIGURE 7
Inductance Coil Design
(patent pend.)

detonators' bridgewire, the fast rise, high frequency firing pulse loses only a small amount of energy through the coil and the majority of the energy is applied to the bridgewire due to the coil inductance. However, for the low frequency 60 cycle current, the inductance coil appears as a direct short and the majority of the energy will pass through the coil rather than the detonator. Physically, our first approach to this design was to form the inductance coil by wrapping wire around the insulated detonator leads. This approach gave us no increase in volume to the detonator and only a minimum increase in diameter of the detonator leads.

III. DESIGN CONCEPT TEST RESULTS

The test program was started by wrapping 28 gauge transformer wire around the detonator leads using from two, to a maximum number of turns (approximately 700) to determine the effect of coil inductance on both the threshold all-fire characteristics of the detonator and the 110 volt A.C. safety characteristics. An example of such a detonator with the coil attached is shown in Figure 8.

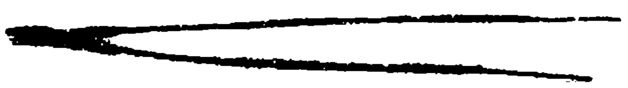


FIGURE 8
Sample Coil Attached RP 87 Detonator

It was first determined how inductance of the coil varied with the number of turns around the insulated detonator leads. These values are shown in Figure 9. The winding of 10.5 inches of coil resulted in approximately 4.5 microhenries of inductance prior to attachment of the bridgewire. After attachment of the bridgewire, the measured circuit inductance substantially reduced. It may be noted that this change in inductance does provide a method to check bridgewire continuity of a completed detonator.

The prime objective of the 110 volt A.C. testing was to simulate as close as possible an actual accidental hookup condition. Equipment was fabricated which contained two standard 20 amp A.C. circuit breakers. The test detonators were connected directly to these breakers. Current through the detonator was monitored using a .05 ohm current viewing resistor and the current wave recorded on an oscilloscope. With one of the 20 amp circuit breakers in the ON position, the second breaker was turned on to subject the test detonator to the 110 volt A.C. current. The test was terminated by self shut-off of the first breaker, or a break in the detonator coil circuit due to overheating.

Figure 10 depicts the average peak current which the test detonators were subjected to. As can be noted, the current reduced as the detonator coil inductance was increased. It should also be noted that the peak current values for the low inductance coils are well above the 275 amp threshold firing current of the detonator. The number of cycles which the detonator was subjected to prior to breakage of the circuit varied from ½ cycle to several cycles. In

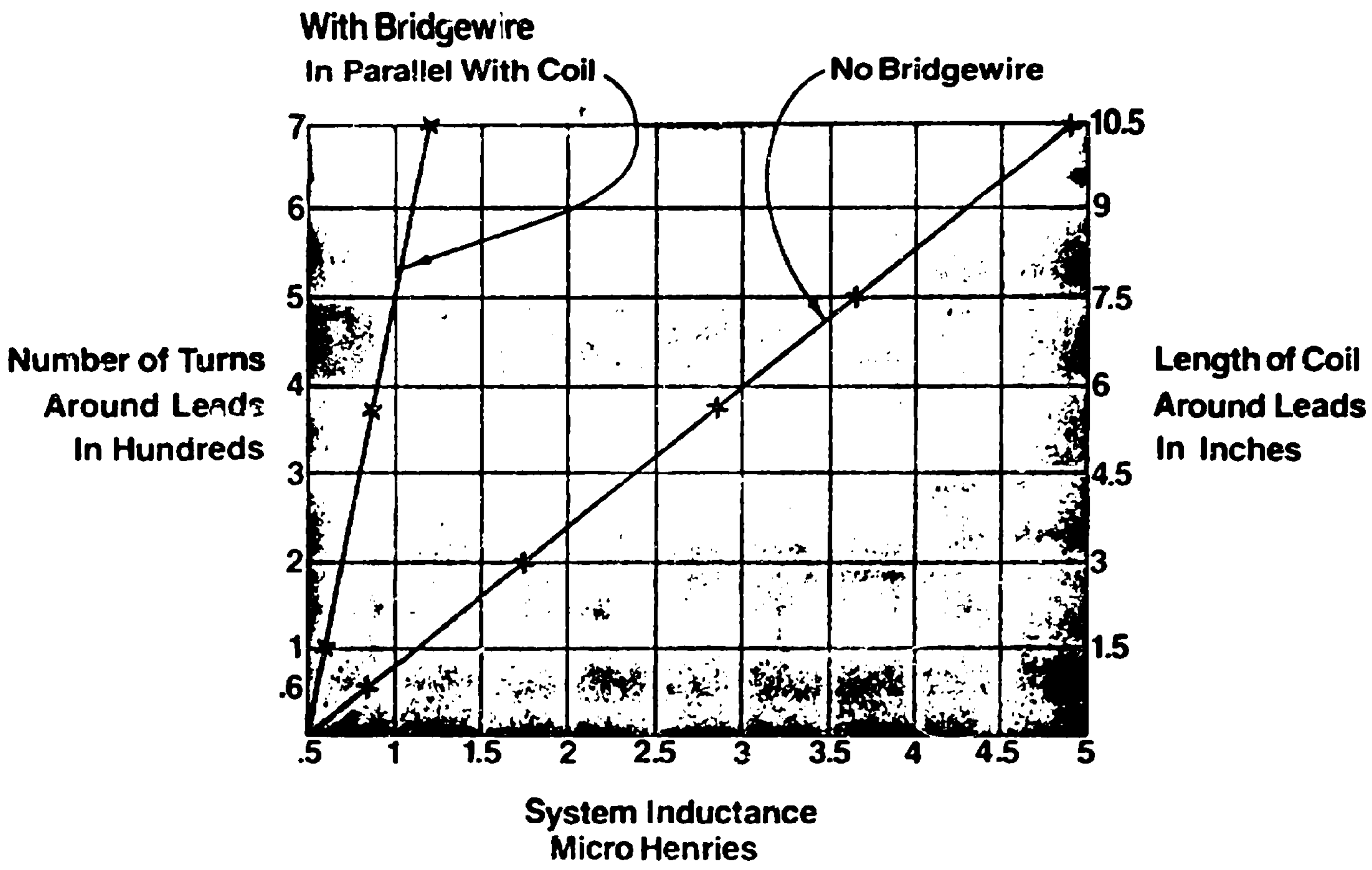


FIGURE 9

INDUCTANCE vs LENGTH OF COIL

28 Gauge Wire

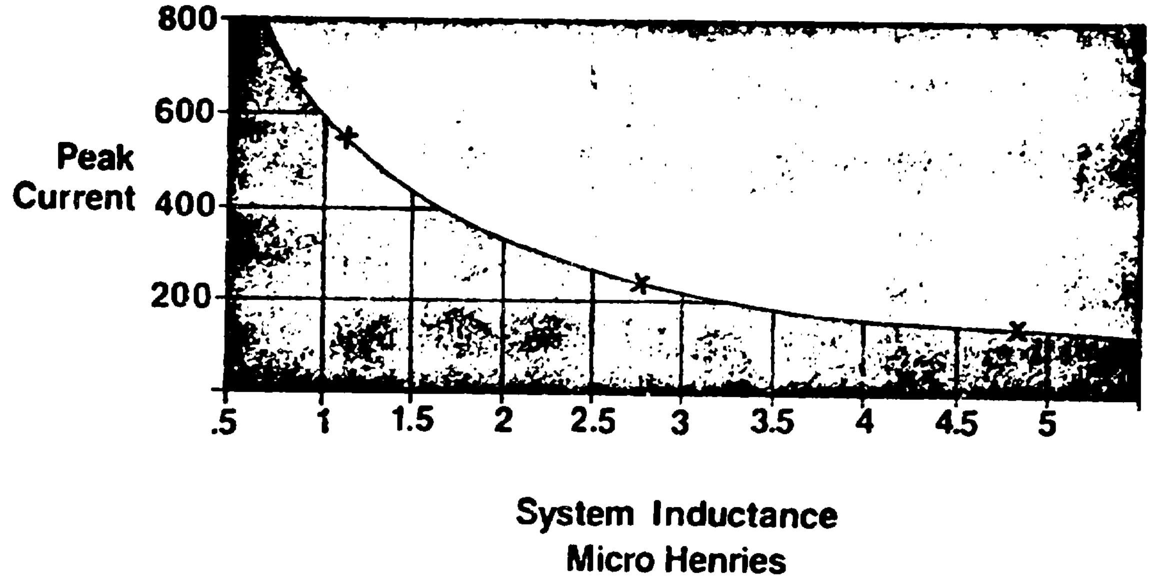


FIGURE 10

Coil Inductance vs Average Peak Current
From Direct Short Into 110 Volt AC Current Source

general, the lower inductance coils shut off the current within one to two cycles whereas the higher inductance systems lasted for several cycles. The turn-on point in the cycle was random since it was felt that a special circuit designed to turn on the current at some particular point in the wave would not as accurately simulate an actual accidental hookup.

During the test program, approximately 120 detonators with various coil inductances were subjected to the 110 volt A.C. current. The coil inductances varied from 12 nanohenries to 4.5 microhenries. Four of these test detonators are shown in Figure 11. Of the 120

FIGURE 11
110 Volts AC Tested Detonators

detonators tested, none presented any explosive response due to the 110 volt A.C. current. Several detonators were subjected to a

significant amount of energy which was evident by an entire burning through of the detonators .020 inch diameter lead wire. The random turn-on of the cycle resulted in current starts in all critical points in the sin wave.

The next step was to look at how this induction coil affected the actual firing characteristics of the detonators. These results are shown in Figure 12. The standard RP-87 detonator has an average threshold voltage of 560 volts using a 1 micro farad capacitor and a normal system inductance of 0.5 microhenries. As can be seen in the curve, the lower inductance coils with approximately 0.5 microhenries of inductance, about doubled the threshold of the detonator up to 1,100 volts. However, the higher inductance coils of around 4.5 microhenries resulted in only nominal increase in detonator threshold voltage.

The results of the testing demonstrates that the induction coil concept in parallel with the detonator bridgewire will protect it from any explosive response if accidentally connected to a low frequency, 60 cycle type input. Also, if this coil is properly designed, no significant change will occur in the threshold firing characteristics of the detonator. Figure 13 shows a comparison of an RP-87 EBW detonator with and without the induction coil. The physical difference amounts to an increase in the diameter of the leads next to the head and a slight reduction in their flexibility. A somewhat different design approach is shown by the third detonator in Figure 13. This design uses a small choke coil in place of the coil wrapped around the detonator leads. Limited testing has shown

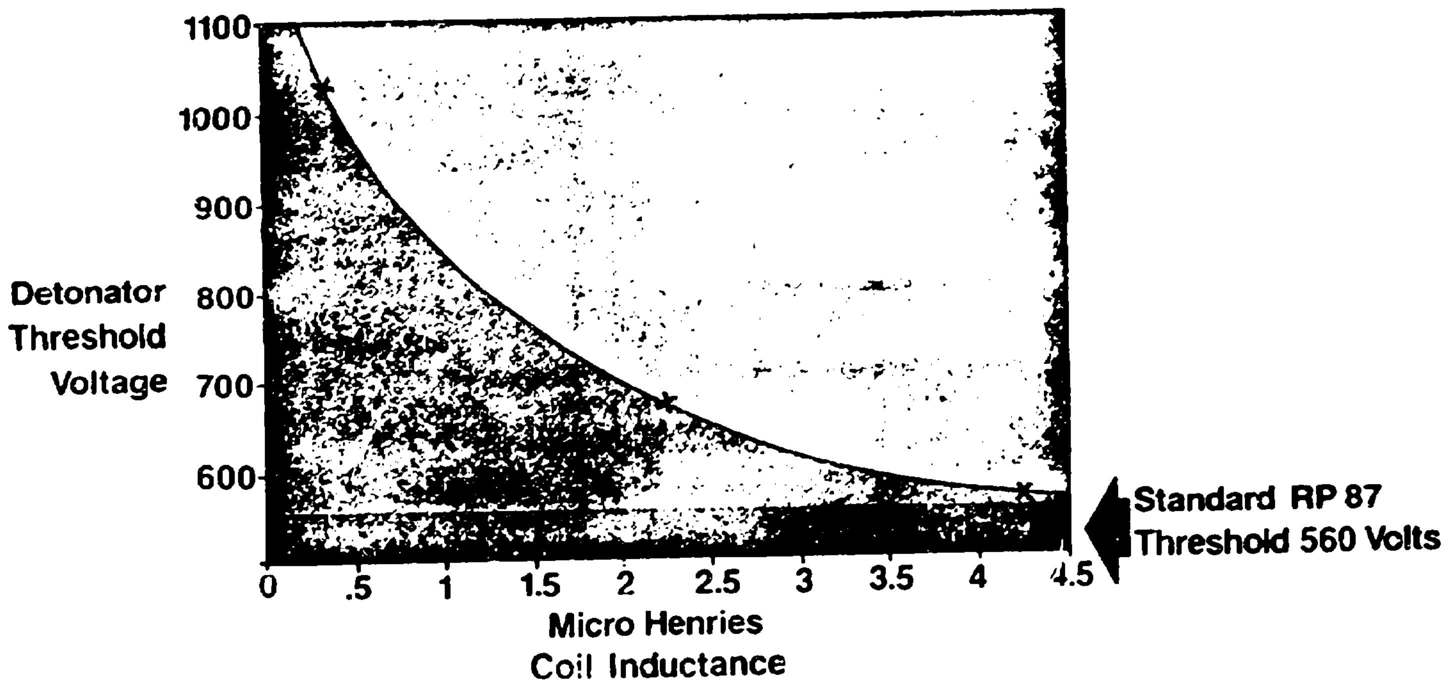


FIGURE 12

RP 87 Detonator

Threshold Voltage vs Coil Inductance

1 Micro Farad Capacitor

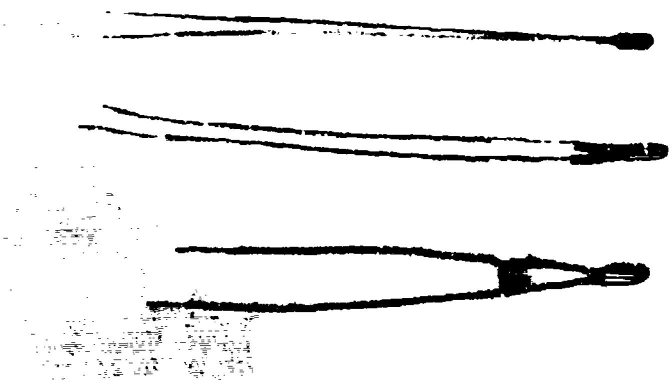


FIGURE 13
RP 87 DETONATOR COMPARISON

that this approach will also provide 110 volt A.C. protection and if properly designed, could be molded into the header of the detonator resulting in no increase in volume due to the coil protection device.

IV. CONCLUSION

This report has presented the design of an electric explosive initiator which has the relatively unique characteristic in that it can be subjected to unlimited current at low frequency and not respond by either a detonation or a deflagration. The addition of the induction coil to accomplish this characteristic is not the critical parameter that makes this type of detonator a safe electrical explosive initiator. The important parameter is that

this BBW detonator contins all secondary explosives which require more than just temperature to cause detonation. It is this fact that makes this detonator inherently safe and allows special design modifications such as the induction coil to be incorporated and used under conditions where a specific potential hazard exists.

Several comments related to this design characteristic were that it is ridiculous to think that a person would plug an explosive detonator into the wall socket. The point that we would like to make is that from a safety standpoint, this type of detonator has some very significant advantages which are impossible with the standard low energy detonator. For example, if your concern is to protect against high frequency, it is possible to design an EBW detonator which will not detonate due to a very fast rise pulse or a slow rise pulse but requires some intermediate pulse envelope to function. (Reference 3) This envelope characteristic can also apply to energy levels. It is our feeling that there are many applications where low energy detonators must be used, but for all applications where safety is of critical importance, EBW detonators should be seriously considered.

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SPONTANEOUS DETONATION OF INITIATORS

Edmund Demberg, Picatinny Arsenal, Dover, N. J.

MY TALK TODAY IS ON THE SPONTANEOUS DETONATION OF INITIATORS. I WILL INDICATE THE SEVERITY OF THE PROBLEM, THE MECHANISM BELIEVED TO BE THE CAUSE AND THE CORRECTIVE ACTION THAT MUST BE TAKEN TO ELIMINATE AND/OR ALLEVIATE THE PROBLEM.

IN DISCUSSING SPONTANEOUS DETONATION, I WILL BE REFERRING TO EXPLOSIONS THAT HAVE OCCURRED IN NON-ELECTRIC DETONATORS AND RELAYS WITHOUT ANY STIMULI FROM OUTSIDE THE PACKAGED ITEMS. IN SEPTEMBER 1961 AT THE LONE STAR ARMY AMMUNITION PLANT APPROXIMATELY 5,000 NON-ELECTRIC INITIATORS, IN AN ISOLATED BARRICADE, EXPLODED WITHOUT APPARENT CAUSE. SINCE THAT TIME THERE HAVE BEEN APPROXIMATELY 20 KNOWN INSTANCES IN WHICH NON-ELECTRIC INITIATORS DETONATED SPONTANEOUSLY. THE SERIOUSNESS OF THIS PROBLEM WENT UNRECOGNIZED FOR MANY YEARS DUE TO THE LOW FREQUENCY OF OCCURRENCES, THE ABSENCES OF PERSONNEL INJURY AND THE RELATIVELY MINOR AMOUNT OF PROPERTY DAMAGE. IN 1968 TO 1970, DUE TO A MAJOR INCREASE IN PRODUCTION, THE PROBLEM BECAME PAINFULLY EVIDENT WITH A RASH OF SPONTANEOUS DETONATIONS, RESULTING IN EXTENSIVE PROPERTY DAMAGE AND LOST PRODUCTION.

THE INITIATORS INVOLVED IN THE SPONTANEOUS DETONATIONS ARE BASICALLY AN EXPLOSIVE PRESSED AND INCLOSED IN A METALLIC CUP. IN GENERAL, THEY ARE CLASSIFIED IN ACCORDANCE WITH THE METHOD OF INITIATION. OUR PARTICULAR INTEREST IS THE STAB OR NON-ELECTRIC INITIATORS. THEY ARE UTILIZED AS

THE COMPONENT OF AN EXPLOSIVE TRAIN WHICH CAN BE ACTIVATED BY EITHER A NON-EXPLOSIVE IMPULSE OR THE ACTION OF A PRIMER. THE INITIATORS ARE CAPABLE OF RELIABLY INITIATING HIGH ORDER DETONATION IN THE SUBSEQUENT HIGH EXPLOSIVE COMPONENT OF THE TRAIN.

WHEN ACTIVATED BY A NON-EXPLOSIVE IMPULSE, AN INITIATOR INCLUDES THE FUNCTION OF A PRIMER. AN EXAMPLE OF SUCH A DEVICE IS THE M55 STAB DETONATOR. IT CONSISTS OF AN INITIAL CHARGE OF NOL 130 PRIMER MIXTURE, AN INTERMEDIATE CHARGE OF RD1333 LEAD AZIDE AND A BASE CHARGE OF RDX. IT IS FUNCTIONED NORMALLY BY THE PENATRATION OF A PIN THROUGH A COINED BOTTOM OF THE ALUMINUM CASE INTO THE PRIMER MIXTURE. THE M55 DETONATOR HAS THE LARGEST RATE OF PRODUCTION OF THE INITIATORS AND HAS BEEN INVOLVED IN THE GREATEST NUMBER OF SPONTANEOUS EVENTS.

EXAMPLES OF ITEMS THAT RELY ON THE ACTION OF A PRIMER TO INITIATE DETONATION ARE THE M17 DETONATOR AND THE XM RELAY. THE M17 DETONATOR HAS AN UPPER CHARGE OF DEXTRINATED LEAD AZIDE AND A LOWER CHARGE OF TETRYL IN AN ALUMINUM CUP. THE M17 HAS A LARGE INVOLVEMENT IN THE SPONTANEOUS INCIDENTS. THE XM RELAY IS THE SIMPLEST DEVICE INVOLVED IN THE SPONTANEOUS DETONATIONS. IT CONSISTS OF A DEXTRINATED LEAD AZIDE CHARGE LOADED INTO AN ALUMINUM CUP. THE XM RELAY HAS PRODUCED THE HIGHEST FREQUENCY OF SPONTANEOUS DETONATIONS.

THE AVERAGE FREQUENCY OF ALL THE EVENTS IS ONE DETONATION IN 80 MILLION MANUFACTURED ITEMS, SEEMINGLY A VERY TOLERABLE RECORD. THE ITEMS ARE SMALL AND IN THEMSELVES, INCAPABLE OF CAUSING ANY SIGNIFICANT AMOUNT OF PROPERTY DAMAGE. THE SAFETY PRECAUTIONS AND SHIELDING INCORPORATED DURING THEIR MANUFACTURE PROVIDE A HIGH DEGREE OF PERSONNEL AND PROPERTY PROTECTION. THESE NON-ELECTRIC INITIATORS ARE HOWEVER, COMMUNAL. AFTER THEIR MANUFACTURE, THEY RESIDE 50 TO A PACK. TWENTY OF THESE BOXES ARE PLACED IN AN OUTER PACKAGE TO GIVE A TOTAL OF 1,000 ITEMS. TEN OUTER BOXES ARE INCORPORATED INTO AN OVER PACK TO BRING THE TOTAL OF ITEMS THAT ARE IN CLOSE PROXIMITY TO 10,000. DURING MANUFACTURE OR PRIOR TO SHIPMENT, INNER OR OUTER BOXES ARE STORED IN REST OR HOLD AREAS WHERE THEIR NUMBER COULD VERY WELL BE INCREASED. AND WHEN THAT ONE INITIATOR IN 80 MILLION DECIDES TO GO OFF IT TAKES ALL ITS NEIGHBORS WITH IT. THE RESULT IS A MASS DETONATION WITH EXTENSIVE PROPERTY DAMAGE AND A THREAT TO PERSONNEL.

IN IOWA ARMY AMMUNITION PLANT ON 27 NOVEMBER 1968, THERE WERE 334,949 M55 DETONATORS IN REST STORAGE. THESE DETONATORS, MANUFACTURED DURING THE DAY AND AFTERNOON SHIFT, WERE BEING PLACED IN REST STORAGE DURING THE PAST 12 HOURS. APPROXIMATELY 30 MINUTES AFTER THE LAST DETONATORS WERE PLACED IN REST STORAGE, AN EXPLOSION OCCURRED RESULTING IN $105,389 PROPERTY DAMAGE.

AT LONE STAR ARMY AMMUNITION PLANT, ON 22 MARCH 1969, AN EXPLOSION OCCURRED IN A TRAILER VAN PARKED IN FRONT OF AN IGLOO. THERE WERE 531,000 DETONATORS IN THE VAN OF WHICH 100,000 WERE M55'S. THE DETONATORS HAD BEEN PLACED IN THE VAN APPROXIMATELY EIGHT HOURS PRIOR TO THE EXPLOSION. THE MINIMUM TIME SINCE MANUFACTURE OF ANY DETONATOR IN THE VAN WAS 48 HOURS. THE PROPERTY DAMAGE RESULTING FROM THE SPONTANEOUS DETONATION WAS $35,411.

ANOTHER EXPLOSION OCCURRED AT LONE STAR ON 17 MAY 1969. THE IGLOO CONTAINED 680,710 REJECTED DETONATORS OF VARIOUS TYPES (M55, M17, M24, M63 AND M50). THE LAST ACTIVITY IN THE IGLOO OCCURRED ON THE 15TH OF MAY 1969.

AT IOWA ON 25 FEBRUARY 1970, AN EXPLOSION OCCURRED INVOLVING OVER 900 LBS OF EXPLOSIVE. IT WAS ATTRIBUTED TO THE SPONTANEOUS DETONATION OF ONE OF 248,850 M17'S OR 4,000 M7'S IN A REST STORAGE BUILDING. SAFETY INSPECTORS HAD CHECKED THE STORAGE BUILDING 2 - 3 HOURS PRIOR TO THE EXPLOSION AND FOUND NO DISCREPANCIES. NO OPERATIONS OF ANY KIND WERE BEING PERFORMED IN THE REST HOUSE OR A SERVICE MAGAZINE, BOTH OF WHICH WERE DESTROYED. THE RESULTING PROPERTY DAMAGE WAS $304,574.

THERE HAVE BEEN SOME SIXTEEN ADDITIONAL INCIDENTS WITH VARYING DEGREES OF LESSER PROPERTY DAMAGE AND MIRACULOUSLY NO INJURY OR LOSS OF LIFE.

UNDER THE DIRECTION OF MUCOM SAFETY OFFICE, THE SPONTANEOUS DETONATION COMMITTEE WAS FORMED AT PICATINNY ARSENAL IN AUGUST 1969. THE COMMITTEE REVIEWED ALL DATA PERTINENT TO THE UNEXPLAINED EXPLOSIONS AND ESTABLISHED AND CONDUCTED A PROGRAM TO DETERMINE CAUSES AND NECESSARY CORRECTIVE ACTION TO STOP OR NEGATE THE DEVASTATING EFFECTS OF SPONTANEOUS DETONATIONS.

IT WAS QUICKLY ESTABLISHED THAT CERTAIN FACTORS WERE CONNON TO ALL THE OCCURRENCES.

1. LEAD AZIDE WAS UTILIZED IN ALL INVOLVED INITIATORS AND IN SOME CASES WAS THE ONLY EXPLOSIVE. LEAD AZIDE IS EXTREMELY SENSITIVE TO ELECTRICAL ACTIVATION. UNDER CERTAIN SPECIFIC CONDITIONS, LEAD AZIDE CAN BE INITIATED WITH AS LITTLE AS 10^{-3} ERGS (4 VOLTS, 20 UUF) OF ELECTRICAL ENERGY. THE SENSITIVITY IS GREATEST IN DRY SAMPLES OF FINE PARTICLES. SENSITIVITY TO ELECTRICAL ACTIVATION IS ALSO INCREASED WITH INCREASES IN THE DENSITY OF A LEAD AIZDE CHARGE.

DRY LEAD AZIDE HAS A LOW CONDUCTIVITY. UNDER CONDITIONS OF LOW HUMIDITY, ELECTROSTATIC CHARGES CAN BE ACCUMULATED ON INDIVIDUAL PARTICLES OF LEAD AZIDE. SUCH ELECTRICAL CHARGES ARE GENERATED DURING DRYING (DRY AIR FORCED THROUGH LEAD AZIDE), SCREENING, DUMPING AND AUTOMATIC DISPENSING OPERATIONS.

2. ALL EXPLOSIONS OCCURRED WITHIN 72 HOURS AFTER MANU-

IS GREATER THAN A HANDLINE. POWDER BUILD UP ON POWDER GUIDES AND PUNCHES CAN LEAD TO VARIATIONS IN THE AMOUNT OF POWDER IN A CUP. FINAL CRIMPING IS DONE TO A FIXED HEIGHT AND EXCESSIVE PRESSURES COULD BE DEVELOPED WITHIN AN ITEM THAT IS LOADED TO THE HIGH SIDE. RECONSOLIDATION OF POWDER CHARGES IS POSSIBLE AT THE FINAL CRIMP STATION.

THE AUTOMATIC EQUIPMENT ALSO DEPOSITS AN EXCESSIVE AMOUNT OF POWDER AROUND THE LOADING STATION AND ON ALL OUTSIDE SURFACES OF THE DETONATOR. GRAPHITE MUST BE EMPLOYED TO LUBRICATE TOOLING AND CUPS TO FACILITATE THE AUTOMATIC LOADING. IT IS ALSO EMPLOYED AS PART OF THE LUBRICANT-BINDER OF SELECTED BASE CHARGE TO AID IN THE AUTOMATIC FEED. IN ADDITION, THERE IS LITTLE OR NO VISUAL OBSERVATION OF THE ITEMS DURING LOADING AS THERE IS ON A HANDLINE. MECHANICAL CONTROLS ARE RELIED ON TO DETECT AND REJECT AN ITEM THAT IS BEING LOADED INCORRECTLY. THIS IS ESPECIALLY CRITICAL IF A DIE IS SCORING THE INSIDE OF A CUP. ALL THESE FACTORS ARE PERTINENT TO THE SPONTANEOUS DETONATION INVESTIGATION.

THE TECHNICAL PROGRAM CONDUCTED BY THE SPONTANEOUS DETONATION COMMITTEE GENERATED SEVERAL THEORIES AS TO THE CAUSE OF THE UNEXPLAINED EXPLOSIONS. THE CAUSES WERE ATTRIBUTED TO EXPLOSIVE CONTAMINENTS OF CUPS, BRITTLE FRACTURE OF WORK HARDENED CUP, CAPACITOR DISCHARGE OF INSULATED DISC AND DECOMPOSITION OF LEAD AZIDE INITIATED BY ULTRAVIOLET LIGHT.

RELAX AND MOVE ABOUT TO RELIEVE THE STRESSES. THIS PROCESS CAN CONTINUE WITH GRADUALLY REDUCED INTENSITY FOR PERIODS UP TO AS LONG AS A WEEK. THE MAJOR MOVEMENT IS ACCOMPLISHED RIGHT AFTER MANUFACTURE.

3. THE METAL CUPS OF THE INVOLVED INITIATORS HAVE BEEN EITHER ALUMINUM OR STAINLESS STEEL. THERE HAVE BEEN NO REPORTED EVENTS INVOLVING ITEMS UTILIZING A GILDING METAL CUP. GILDING METAL CUPS ARE MADE OF A COPPER ALLOY AND ARE ALWAYS SHELLAC COATED ON THE INTERIOR SURFACE, PRIOR TO LOADING. THE SHELLAC COATING WOULD ACT AS AN INSULATOR AND PREVENT ANY RAPID DISCHARGE AT THE INTERFACE OF THE LEAD AZIDE AND METAL CUP. THE GILDING METAL CUP IS ALSO SOFTER THAN THE ALUMINUM OR STAINLESS STEEL. IT WOULD HAVE MORE OF A TENDENCY TO GIVE AND PREVENT OR RELIEVE STRESSES IN CONSOLIDATED CHARGES.

4. ONLY NON-ELECTRIC INITIATORS ARE INVOLVED IN THE SPONTANEOUS DETONATIONS. THIS PHENOMENA MAY ONLY BE A TEMPORARY SITUATION. THE PRODUCTION OF ELECTRIC INITIATORS IS NOT AS GREAT AS THE NON-ELECTRIC VARIETY. A LARGE PORTION OF ELECTRIC INITIATORS IS NOT MANUFACTURED ON THE HIGH SPEED, HIGH VOLUME LOADERS. THE HIGH INTERNAL PRESSURES ASSOCIATED WITH THE NON-ELECTRIC ITEMS ARE NOT INCORPORATED INTO ELECTRIC ITEMS. WITH INCREASES IN PRODUCTION AND AUTOMATION, THE POSSIBILTTY OF A SPONTANEOUS DETONATION GROWS. IT MIGHT BE

A GOOD TIME TO LOOK INTO PREVENTIVE MEASURES FOR ELECTRICAL DEVICES.

5. TWO OF THE THREE PLANTS LOADING ARMY NON-ELECTRIC INITIATORS HAVE EXPERIENCED SPONTANEOUS DETONATIONS. KANSAS ARMY AMMUNITION PLANT HAS NEVER HAD AN EXPLOSION THAT COULD BE ATTRIBUTED TO SPONTANEOUS DETONATION. ALTHOUGH KANSAS AAP HAS NOT PRODUCED THE QUANTITIES THAT LONE STAR OR IOWA HAS, IT HAS MANUFACTURED SUFFICIENT NUMBERS TO STATISTICALLY PREDICT AN INCIDENT. A REVIEW OF PLANT PROCEDURES INDICATED DIFFERENCES BETWEEN KANSAS AND THE OTHER PLANTS. THE AREA THAT SEEMED MOST PERTINENT TO THE SPONTANEOUS DETONATION SUTDY WAS KANSAS PROCUREMENT, INSPECTION AND REWORK OF TOOLING.

6. THE APPEARANCE OF SPONTANEOUS DETONATIONS COINCIDED WITH THE INTRODUCTION OF AUTOMATIC LOADING DEVICES. HAND-LINE OPERATIONS WERE AUTOMATED AND INCORPORATED INTO A JONES LOADER. THE RAW MATERIALS ARE FED INTO A JONES AND FINISHED INITIATORS COME OUT.

TWO AUTOMATIC DISPENSING DEVICES, THE FRICTIONLESS AND THE CHAMLEE, WERE DEVELOPED FOR DISPENSING LEAD AZIDE. BOTH SYSTEMS IMPART A GREAT DEAL OF MOVEMENT TO THE LEAD AZIDE BEFORE POURING A MEASURED AMOUNT INTO A CUP. THE CARGILE LOADER, WHICH SIMULATES THE HAND SCOOPING OPERATION, IS EMPLOYED TO METER OUT PRIMER MIX. IN ALL CASES OF METERING DEVICES, THE TOLERANCE ON THE AMOUNT OF POWDER IN A CHARGE

IS GREATER THAN A HANDLINE. POWDER BUILD UP ON POWDER GUIDES AND PUNCHES CAN LEAD TO VARIATIONS IN THE AMOUNT OF POWDER IN A CUP. FINAL CRIMPING IS DONE TO A FIXED HEIGHT AND EXCESSIVE PRESSURES COULD BE DEVELOPED WITHIN AN ITEM THAT IS LOADED TO THE HIGH SIDE. RECONSOLIDATION OF POWDER CHARGES IS POSSIBLE AT THE FINAL CRIMP STATION.

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THE THEORIES WERE REVIEWED, EVALUATED, REVISED AND RESOLVED INTO THE CURRENT PROPOSED MECHANISM FOR THE CAUSE OF SPONTANEOUS DETONATORS.

LEAD AZIDE IS THE PRIME SUSPECT. THE EXTREME ELECTRICAL SENSITIVITY IS THE BASIS FOR CONSIDERING THE SPONTANEOUS EXPLOSIONS ARE A RESULT OF THE ELECTRICAL ACTIVATION OF LEAD AZIDE.

THIS THEORY POSTULATES THE GENERATION OF AN ELECTROSTATIC CHARGE ON LOOSE LEAD AZIDE DURING PROCESSING AND LOADING. ON CONSOLIDATION, THESE CHARGES ARE TRAPPED IN THE LEAD AZIDE CHARGE IN THE INTERIOR OF THE CUP. THE ELECTRICAL CHARGE, ALTHOUGH IN A MATRIX OF HIGH RESTIVITY, WILL MIGRATE OUTWARD TO THE BARE METAL SURFACE OF THE CUP. THIS MIGRATION IS ENHANCED BY THE GRAPHITE IN THE LOADED ITEMS AND THE MOVEMENT OF CRYSTALS TRYING TO RELIEVE INTERNAL PRESSURES. WHEN A FLOW OF ELECTRONS ENTERS A CRYSTAL OF LEAD AZIDE WITH SUFFICIENT ENERGY, DECOMPOSITION AND EXPLOSION RESULT.

THE CONCURRENT PROGRAM TO PREVENT THE DEVASTATION OF A SPONTANEOUS DETONATION SHOWED IMMEDIATE AND STRIKING BENEFITS. UNDER THE SPONTANEOUS DETONATION PROGRAM, PACKAGING FOR NON-ELECTRIC INITIATORS WAS DESIGNED TO PREVENT MASS DETONATION IN THE EVENT OF A SPONTANEOUS EXPLOSION. THE INITIAL STUDIES CONDUCTED AT LONE STAR ARMY AMMUNITION PLANT PRODUCED A PACK FOR THE M55 DETONATOR THAT WOULD PREVENT A SPONTANEOUS

DETONATION OF ONE ITEM FROM PROPAGATING TO A DETONATOR IN ANY OTHER BOX. THIS M55 PACK WAS SCALED UP AND MODIFIED TO PRODUCE A FAMILY OF NON-PROPAGATING PACKS FOR NON-ELECTRIC INITIATORS.

THE BASIC CHANGES IN THE PACKAGING TO OBTAIN NON-PROPAGATION WERE AS FOLLOWS:

1. THE SPACER WAS MADE SUFFICIENTLY THICK TO ENABLE THE ITEM TO BE PACKED FLUSH WITH OR BELOW THE TOP SURFACE.

2. THE FILLER WAS CHANGED FROM CORRUGATED PAPER TO A FELT PAD BACKED BY A PAPER BOARD STIFFNER.

3. THE SLIDE COVER WAS MADE TO PROVIDE A SNUG FIT TO INSURE ITEMS ARE HELD FLUSH OR BELOW.

4. AN ADDITIONAL PAPER BOARD STIFFNER WAS GLUED TO THE OUTSIDE OF THE SLIDE COVER TO PREVENT VERTICAL PROPAGATION.

5. THE SPACER WAS GLUED 100% ON CONTACT SURFACES TO PREVENT HORIZONTAL PROPAGATION BETWEEN DETONATORS.

6. DISTANCES BETWEEN CENTERS OF HOLES WERE DESIGNATED TO PROVIDE SUFFICIENT MATERIAL BETWEEN INITIATORS TO PREVENT PROPAGATION.

7. HOLES IN ADJACENT BOXES WERE STAGGERED AND BOXES WERE COLOR CODED TO INSURE THEY WERE POSITIONED CORRECTLY IN THE OUTER PACK.

8. DRAWINGS AND SPECIFICATIONS WERE PREPARED TO DESIGNATE MATERIALS AND CONSTRUCTION TO INSURE NON-PROPAGATING FEATURES.

THE VALUE OF THE NON-PROPAGATING PACKAGE WAS DEMONSTRATED ALMOST IMMEDIATELY AND WITH REMARKABLE CLARITY. WHERE THE SPONTANEOUS DETONATION OF A SINGLE INITIATOR HAD RESULTED IN HAVOC, IT NOW WAS REGULATED TO AN OCCURRENCE THAT PRESENTS LITTLE THREAT TO PROPERTY OR PERSONNEL.

ON 11 SEPTEMBER 1970 AT LONE STAR AAP, THE FIRST SPONTANEOUS EXPLOSION OCCURRED TO AN ITEM PACKAGED IN THE NEW NON-PROPAGATING BOX. M17 DETONATORS WERE MANUFACTURED AND PLACED IN STORAGE. THE NEXT MORNING AN OPERATOR REMOVED A NUMBER OF PACKS AND TRANSFERRED THEM TO A PAINTING AREA. ON OPENING THE BOXES, THE OPERATOR DISCOVERED THE EXPLODED DETONATOR. NONE OF THE OTHER DETONATORS EXPLODED IN EITHER THE SAME BOX OR IN ADJACENT BOXES. COST - NEGLIGIBLE!

A SECOND OCCURRENCE TOOK PLACE AT LONE STAR INVOLVING THE M55 (ACTUALLY THE MK49 NAVY VERSION OF THE M55). A SPONTANEOUS DETONATION WAS DISCOVERED ON THE 6TH OF APRIL IN A PACKAGE OF M55'S, THAT HAD BEEN PUT IN STORAGE ON THE 2ND OF APRIL 1971. THE NEW SAFETY PACKAGE LIMITED THE EXPLOSION TO THE ONE DETONATION. COST INSIGNIFICANT!

AS A RESULT OF THE SPONTANEOUS DETONATION PROGRAM, CERTAIN CONTROLS WERE INSTITUTED ON THE MANUFACTURE OF INITIATORS TO PREVENT OR CONTAIN THE SPONTANEOUS DETONATIONS.

1. NON-PROPAGATING PACKS WERE DESIGNED AND DESIGNATED FOR NON-ELECTRIC INITIATORS.

2. FRESHLY MANUFACTURED ITEMS WERE PLACED IN A REST AREA FOR 24 HOURS.

3. HUMIDITY CONTROLS WERE IMPOSED TO PREVENT A DRY ATMOSPHERE WHILE PROCESSING OR LOADING LEAD AZIDE.

4. PROCEDURES, SPECIFICATIONS, DRAWINGS AND DOCUMENTS USED AT KANSAS AAP FOR THE PROCUREMENT AND REWORK OF TOOLING USED IN THE JONES LOADER WERE RECOMMENDED FOR ADOPTION AS STANDARD FOR ALL LOADING PLANTS.

5. ALL CUPS WERE STRESS RELIEVED AND SHARP RADII WERE REQUIRED AT THE CORNER OF THE CUP TO PREVENT DEVELOPMENT OF STRESSES DURING LOADING.

6. A "BREAK-AWAY" WAS REQUIRED AT THE FINAL CRIMPING OPERATION TO CONTROL THE PRESSURES APPLIED TO AN INITIATOR.

IN ADDITION, STUDIES ARE BEING CONDUCTED TO DETERMINE APPLICABILITY OF ESTABLISHING OTHER CONTROLS TO ELIMINATE SPONTANEOUS DETONATION.

1. SPECIFYING BOTH A MIN AND MAX REQUIREMENT ON THE MOISTURE CONTENT OF LEAD AZIDE.

2. TREATING LEAD AZIDE WITH ANTI-STATIC AGENT TO PREVENT BUILD-UP OF A CHARGE.

3. MONITOR THE INDIVIDUAL CHARGES OF LEAD AZIDE AS THEY ARE BEING PLACED INTO AN INITIATOR CUP TO DETECT THE PRESENCE OF AN ELECTROSTATIC CHARGE.

4. ELIMINATE USE OF GRAPHITE.

5. COAT LOADING TOOLS TO NEGATE LUBRICANT, PREVENT SCORING AND STOP POWDER BUILD-UP ON POWDER GUIDES AND CONSOLIDATING PUNCHES.

6. COAT THE INTERIOR SURFACES OF INITIATOR CUPS WITH AN INSULATING MATERIAL.

7. REMOVE FINE PARTICLES OF LEAD AZIDE.

8. REMOVE UP-STAND; THE POWDER BUILD-UP ALONG THE INTERFACE OF THE CUP AND DIE AT EACH CONSOLIDATION.

IN CONCLUSION, I WOULD LIKE TO EMPHASIZE, ALTHOUGH THE DEVASTATING EFFECTS OF SPONTANEOUS DETONATION HAVE BEEN ALL BUT NULLIFIED, THE CAUSE IS ONLY POSTULATED AND THE THREAT STILL EXISTS. THE SPONTANEOUS DETONATION COMMITTEE IS CONTINUING ITS MONITORING AND ITS STUDIES. TIME WILL TELL IF THE POSTULATED THEORY AND ESTABLISHED CONTROLS HAVE ELIMINATED SPONTANEOUS DETONATION IN INITIATORS.

IMPACT SENSITIVITY OF COMMERCIAL DETONATORS

Karl R. Becker, John C. Cooper and Richard W. Watson
Pittsburgh Mining and Safety Research Center, Bureau of Mines,
U. S. Department of the Interior, Pittsburgh, Pennsylvania 15213

ABSTRACT

A variety of blasting caps (electric and nonelectric, instantaneous and delay types) manufactured by various domestic and several foreign companies were subjected to impact tests along the length of the detonator to find the most sensitive area. The detonators were impacted by a 2.36-kg drop weight having a 0.635-cm-diam flat striking surface. Resistance to initiation by impact varied widely among the detonators; threshold initiation limits ranging from 3.47 to 20.82 joules (2.6 to 15.4 ft-lb) were observed for the most sensitive regions. The friction sensitivities of the various explosive components in some detonators were also determined. The friction sensitivity of the explosive component utilized was an important parameter in determining sensitivity; in addition, various construction features of nonexplosive components are also important in determining the impact sensitivity of a given detonator. Typically, a detonator relatively sensitive to impact in a given localized region is one where a relatively sensitive component is situated in an air cavity inside the detonator protected only by the outer case and without any inner supports in the vicinity of impact. The use of inner sleeves (plastic, metal, etc.) surrounding the component and/or supports closely spaced on either side of the component is quite effective in reducing the impact sensitivity in that region.

INTRODUCTION

Manufacturers of detonators perform a variety of tests on their products. Some tests are for quality-control purposes and for developing new products to meet the needs of industries; other tests are carried out in the interest of safer products. Among these are tests to evaluate impact hazards; the results are not generally published but are used for comparisons with standards established by each company. The Bureau of Mines, having both a keen interest and a responsibility for safer products used in the mining industries, has carried out a series of impact experiments on detonators and is making available for publication its findings on this topic. It should be pointed out that the main purpose of this work was to gather information in the interest of safety and not to grade detonators manufactured by the various companies. In view of this, the trade and/or company designations of the products have been omitted.

EXPERIMENTAL TECHNIQUES

The drop-test apparatus, shown in figure 1, utilized a steel drop weight, 6.35 cm in diameter by 9.7 cm long, having a mass of 2.36 kg. The falling weight was guided inside a 6.35-cm-diam by 1.25-m long, 0.65-cm wall, plastic tube supported in a vertical position by two steel rods anchored in a steel base plate 25 cm in diameter by 10 cm thick. Three types of impacts were conducted: (1) an impact where the detonators were impacted lying flat (horizontally) and struck by the 6.35-cm diam flat-bottom surface of the drop weight; (2) a vertical impact where the detonators were placed in the vertical position and struck by the 6.35-cm-diam flat-bottom surface of the drop weight; and (3) a localized impact in which a 0.635-cm-diam by 3.8-cm-long cylindrical steel pin was inserted in the bottom face of the drop weight for impacts on selected regions along the length of the detonator to determine the most sensitive spot; e.g., ignitor, delay element, primary, or base charge regions. The impact surfaces of the drop weight (pins and base discs)

were expendable and could easily be replaced.

For a test, the detonator was placed on a 10 by 10 by 2.54-cm thick steel plate (also expendable) that rested upon the large steel base. The weight was raised remotely by means of a calibrated, waxed cord. Drop heights were precise to within 1.0 cm, and the impact velocities were found to be within 5% (less) of the theoretical drop velocities.

Sketches of several representative detonator types are shown in figure 2. These sketches and the brief discussion that follows are not intended to elucidate all the intricacies of detonator designs; rather, they simply show the basic elements of a blasting cap, an instantaneous electric blasting cap (EBC), and two slightly different designs for delay EBC's.

Figure 2-A shows a blasting cap; the upstream end has an open well that accepts the fuse. Then, in a downstream direction, are the ignition, primary, and base explosive elements.

A representative instantaneous EBC is shown in figure 2-B. It is similar to the blasting cap except that the ignition charge is ignited by an electrically heated bridge wire; the upstream end contains leg wires held in place by rubber or plastic plugs.

The chemical composition of the ignition, primary, and delay elements are many and varied; however, ignitor components in general are relatively heat-sensitive and primary explosives, of course, are sensitive to a variety of stimuli including heat, friction, and impact. The base explosives are secondary explosives and with few exceptions are either PETN or PETN-graphite.

The main feature of a delay EBC is shown in figure 2-C; it has four active components, the extra one being the delay element which is always located immediately downstream from the ignition charge. The delay period for members of a given delay series is varied by changing the length, loading pressure, and composition of the delay element.

Figure 2-D illustrates a delay EBC that had five active components. Relative to the preceding delay detonator, the extra component is a second ignition element situated between the delay and primary components. It is utilized when the delay element is not a good ignitor for the primary charge. Some blasting caps and instantaneous EBC's utilize only two explosive components--a combination ignition-primary and base components.

Experimental Results and Discussion

Impacts using the 6.35-cm-diam broad-surface tool

Horizontal and vertical impact trials were conducted primarily for screening purposes and to compare the extent of damage to various detonators under constant-impact energy and also to gain some insight as to the amount of deformation detonators could sustain without reacting. Twenty-seven different detonators from 8 different manufacturers were impacted by the 2.36-kg weight at a 100-cm drop height. The different types tested were EBC's, both instantaneous and delay, and blasting caps. Five repeat trials were made on the detonators lying flat and standing vertically; in both cases the leg wires were removed prior to impact. Preliminary trials conducted in the vertical impact mode with the drop weight striking the upper (leg wire, fuse) end of the detonator or the lower (base charge) end produced similar results. In the screening tests, three trials were conducted with the drop weight striking the upper end and two trials with the weight striking the lower end.

Several different detonators that were deformed in the broad surface impact trials are shown in figure 3. Figure 3-A, from left to right, shows an instantaneous EBC before impact and two similar detonators that were impacted in the horizontal and vertical modes. The degree of deformation, i.e., flattening in the horizontal impact and axial compression and rupture in the vertical impact, is moderately severe and is fairly typical for most detonators. However, for a variety of reasons that in-

clude the detonator size, case strength, inner component construction or a combination of these and other features, the amount of deformation varied somewhat. Figure 3-B shows a blasting cap having an aluminum case that sustained very severe deformations in both vertical and horizontal modes; figure 3-C is a delay EBC that sustained only slight deformation in the horizontal mode.

Results of all the impacts using the 6.35-cm-diam broad-surface tool are summarized in table 1 using coded designations for manufacturer and appropriate notations to designate detonator type. As will be noted, ignitions occurred in only 4 of the 27 detonators tested. Of these, two are no longer in production; one was an outdated foreign product and the other was a relatively small-size military item. The significant observations in these screening trials were that all the modern detonators tested and in use at the present time could sustain quite severe deformations, under this type of impact, without initiating.

<u>Localized impacts on detonators</u>

Twenty different detonators made by 7 different manufacturers were subjected to localized impacts. Among these were instantaneous EBC's, delay EBC's and blasting caps. The locations of given explosive components within the detonator were determined from radiographs, company sketches, and measurements obtained from detonators that were disassembled at the Bureau.

The location of the impacts was varied along the length of the detonators to find the most sensitive region; e.g., ignitor, delay element, primary, or base charge. The force of impact was transmitted to a specific area of the detonator via a steel pin having a 0.635-cm-diam flat striking surface. The pin was rigidly recessed into the base of the drop weight. The drop-height interval used was 5 cm, and total drop heights are accurate to ± 1 cm.

Results from the localized impacts are presented in table 2 in terms

of the threshold initiation limit (TIL), which is the highest drop-height interval at which five successive failures occurred for impacts in the most sensitive region. The detonators exhibited a relatively wide range of impact sensitivities yielding TIL values ranging from 15 to 90 cm with corresponding impact energies of 3.47 and 20.82 joules (2.6 and 15.4 ft-lb). As will be noted in certain cases (detonators with Key Nos. 1423, 488, and 8005), the ignition charge and primary charge were in such close proximity that they were both influenced by the striking pin during a single impact and, consequently, the specific component leading to observed TIL could not be identified. In one other case (Key No. 1297), the ignition and primary mixtures were combined into a single component. In general, the primary or "ignition-primary" charges were associated with the most sensitive impact regions. However, there were important exceptions. The most sensitive regions of detonators having Key Nos. 1373, 1465, 1466, 1099, 965D, 1473, 1424A and 1424C contained the ignition charge. In fact, the detonator with Key No. 965D exhibited the highest sensitivity (lowest TIL value) of any of those tested. In another case (Key No. 1397C), the most sensitive region was associated with the delay train.

Before elaborating on these results, it should be pointed out that the conceivable parameters affecting resistance to ignition by impact are numerous. Among them are the inherent sensitivity of the explosive used, the thickness and strength of the outer case, the protection offered by inner shells or sleeves surrounding explosive components, and suspension points immediately outside the impact area of interest. Without detailed knowledge or precise control of these parameters, the relative standings of all the TIL values obtained cannot be accounted for in precise fashion. In an effort to gain additional insight into the factors influencing the impact sensitivity, selected detonators were disassembled and sensitivity tests were run on the various explosive components. In addition, a careful examination was made of the physical characteristics of the detonators that might effect sensitivity.

Effect of explosive sensitivity

Both drop-weight and friction-sensitivity tests were conducted on the various active components extracted from disassembled detonators. The drop-weight tests were conducted on the Bureau's impact tester for solid materials[1/]. The friction tests were run on a friction tester developed by the German Federal Institute for Materials Testing (Bundesanstalt fur Materialprufungen, BAM). With this apparatus, small samples of the material under investigation are placed between a stationary porcelain pin and a moving porcelain plate, both having a standard roughness. The pin is rounded at each end and is mounted on a lever arm upon which 1 of 9 weights may be placed in 1 of 6 positions providing a total of 54 load increments ranging from 0.5 to 36.0 kg. For a test, a switch is thrown and the anvil, upon which the porcelain plate is mounted, reciprocates once to and fro and automatically shuts off. The relative sensitivities of the explosives are ranked in terms of a TIL, which is the maximum load in kilograms resulting in no reactions in five trials.

Despite precautions, the samples of the active components extracted from detonators did contain very small amounts of contaminants from adjacent components. In some cases, this led to unreasonable drop-weight test results, and for this reason the impact test data will not be reported here. For the friction tests that utilized sample sizes an order of magnitude less than that required for the drop-weight tests, it was possible, through painstaking efforts, to remove foreign particles from the test samples, which resulted in reproducible test results that were in essential agreement with extant data when such comparisons could be made. The friction test results are summarized in table 3 along with the TIL values at the most sensitive region, which were taken from table 2.

The most important feature of the data in table 3 is the fact that in every case the most sensitive region of a given detonator was associated with the component (components) having the highest friction sensi-

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1/ Mason, C. M. and E. G. Aiken. Methods for Evaluating Explosives and Hazardous Materials. BuMines IC 8541, 1972, 48 pp.

tivity. Thus, the inherent sensitivity of the most sensitive material plays a dominant role in determining the impact sensitivity of a given detonator. However, for the various items tested there was no apparent correlation between the TIL values observed in the drop-weight tests on detonators and the friction tests of the explosive components. This latter observation indicates the importance of the external and internal construction features of detonators in determining impact sensitivity. The excellent correlation between the most sensitive region and the friction sensitivity of the material contained in that region indicates that friction is an important initiation mechanism for detonators exposed to mechanical impact. This is not too surprising since large frictional forces with attendant localized heating must occur during the massive deformation process.

Outer case effect

The resistance to deformation of the outer case of the detonator should have an effect on the detonator's resistance to initiation by impact. The effect is demonstrated by the data presented in tabular form below for two blasting caps. Blasting caps were chosen for the comparison because their construction is simple and free of possible effects from bridge wires and supports in or near the vicinity of impact. The data clearly show a correlation between the outer case thickness and resistance to initiation by impact for constant explosive sensitivity. This is further illustrated in figure 4, which shows localized and broad impacts on the two detonator types. The detonator with the 0.007-inch-thick case suffers much more serious deformation in both instances.

Detonator designation	Friction sensitivity (kg)	Outer case thickness (mils)	TIL for impact on detonator (cm)
488	0.5	9	50
8005	0.5	7	25

Effect of internal construction features

Protection offered by inner shells was in some instances quite marked. The additional resistance to deformation offered by inner shells is demonstrated using the detonator designated in table 2 as 1397C, delay EBC, 100 msec. The basic features of this detonator are the same as that depicted in figure 2-C. The sketch shows a bridge wire element immersed in an ignition charge; downstream from this region is a delay element, a primary charge surrounded by an inner shell, and then a base explosive charge. Pertinent data that illustrate the inner case effect are given in the following tabulation; the results were obtained from localized impacts on the areas containing the primary and delay elements using the same detonator type. The friction sensitivities of the primary and delay elements were the same, but the primary element was protected by an inner case; hence, impacts on this region of the detonator produced a TIL value of 90 cm as opposed to 45 cm for the delay element region.

Detonator designation	Explosive component	Friction sensitivity (kg)	TIL for impact on detonator (cm)
1397C	Primary	1.0	90
	Delay	1.0	45

Figure 5 shows impacts, at constant drop height, upon an outer case (5-A) and upon the outer case and inner shell together (5-B) of detonator 1397C; the explosives had been removed for the demonstration. The additional resistance to deformation provided by the inner shell is significant.

In other instances, e.g., as with the detonator designated 965D (fig. 2-D), an inner shell surrounding one component will provide protection to other unprotected explosive components if the impacting surface is large, as was the case in the broad impacts discussed earlier. In particular, this detonator had a very sturdy brass cylinder surrounding a relatively insensitive delay explosive component (friction sensi-

tivity 36 kg or greater); this cylinder together with the end plug provided protection for a very sensitive (friction sensitivity 0.5 kg) composition used as an ignition element. In broad impacts, this detonator sustained relatively little deformation (fig. 3-C), yet localized impact trials on the ignition region using the 1/4-inch-diam tool produced the lowest TIL value (TIL = 15 cm) of any region in any detonator tested.

It is instructive to examine some of the features of this detonator and another one in the same delay series (1473). Data pertinent to the discussion are shown in the following tabulation. The friction sensi-

Detonator designation	Most sensitive area	Friction sensitivity (kg)	TIL for impact on detonator (cm)
965D (175 msec)	Ignition charge	0.5	15
1473 (500 msec)	do.	< 0.5	35

tivities of the ignition elements are believed to be about the same since in five trials with a 0.5-kg load no ignitions were observed for the 175-msec detonator and only one ignition for the 500-msec detonator. Their construction features from the upstream end down to their delay components appear to be identical; i.e., their case thicknesses are the same (9 mils), and the ignition elements in both detonators are situated in a long air cavity and are the same distance from the upstream end of the detonators. In both cases the ignition elements were contained in inner sleeves. For the 175-msec detonator, it was a cardboard sleeve, 13/16 inch long with a wall thickness of about 13 mils; for the 500-msec detonator, the sleeve appeared to be polyethylene having a length of about 15/16 inch and a wall thickness of about 16 mils. Quite likely, the added protection provided by the thicker plastic sleeve was the main factor responsible for the significant difference in the impact TIL values of 15 and 35 cm.

Lastly, it would be instructive to discuss briefly some of the pertinent features of the detonator that was least sensitive to initiation in the localized impacts. The detonator in question was designated 1464, delay EBC, 500 msec. and had four active elements: ignition, delay, primary, and base charges. The friction sensitivity data in table 3 show sensitivity values for ignition, delay, primary, and base charges of 8, >36, <0.5, and 4 kg, respectively, for these components. With the exception of the primary explosive, the other elements were relatively insensitive. Strictly on this basis, one would not expect the regions of the detonator containing these insensitive components to be very sensitive to impact; this was the case. The most sensitive region, the primary region, was in itself quite insensitive considering that it contained such a sensitive explosive; the TIL value for impacts on this region was 90 cm. This is a good example where there was limited access to a sensitive explosive. One could not impact the primary explosive with the 1/4-inch-diam tool without engaging the delay element immediately upstream (which was surrounded by a sturdy inner cylinder) or the base charge immediately downstream or both. It was observed that the primary region was most vulnerable to impacts centered so that all the tool overlap was upon the base charge and none upon the inner metal cylinder around the delay charge. Even so, it is quite conceivable that the metal cylinder, though immediately outside the area of impact, lent some support against deformation of the outer case since it represented a close support or suspension point for impacts in that immediate neighborhood.

SUMMARY AND CONCLUSIONS

From the earlier screening trials where forces of impact were distributed over wide areas of the detonators, it was observed that most detonators could sustain severe deformations without initiating; the amount of deformation, at constant impact energy, varied markedly depending upon various constructive features of the detonators.

In localized impacts, it was found that the most sensitive region

TABLE 1. - Data for impacts using the 6.35-cm-diam broad-surface tool

Detonator identification (Key No.)	Remarks	Results at 100-cm drop height	
		Horizontal impact	Vertical impact
	MANUFACTURER 1		
1225	Instantaneous EBC, No. 6	5 failures	5 failures
1373	Instantaneous EBC, No. 8	do.	do.
1398B	Delay EBC, 100 msec	do.	do.
1464	Delay EBC, 500 msec	do.	do.
1423	Fuse type, No. 6, aluminum case	do.	do.
	MANUFACTURER 2		
1297	Instantaneous EBC, No. 6	do.	do.
1397C	Delay EBC, 25 msec, No. 8	do.	do.
9716A	Delay EBC, 135 msec	do.	do.
1465	Delay EBC, 500 msec, No. 8	do.	do.
1466	Delay EBC, 2.9 sec, No. 8	do.	do.
9000	Fuse type, No. 6	do.	do.
9001	Fuse type, No. 8, aluminum case	do.	do.
8695	Fuse type	do.	do.
	MANUFACTURER 3		
1099	Instantaneous EBC	do.	do.
965D	Delay EBC, 175 msec	do.	do.
1473	Delay EBC, 500 msec	do.	do.
488	Fuse type, No. 6	do.	do.
489	Fuse type, No. 8	do.	do.

of the detonator invariably corresponded to the area containing the element exhibiting the highest friction sensitivity, indicating that the impact sensitivity of those detonators tested was dictated by the inherent sensitivity of the most sensitive component regardless of construction features.

The most sensitive area of detonators exposed to localized impacts did not always correspond to the region containing the primary explosives. In many cases the ignition element dictated the sensitivity to localized impacts.

Widely different values of impact sensitivity were observed with different detonators containing explosives having the same friction sensitivity; this indicates that the construction details play an important factor in determining impact sensitivity.

Although it is doubtful that the inherent sensitivity of the active materials used in detonators can be significantly altered, the avoidance of large air spaces and the use of protective sleeves and more rigid outer cases are measures that could be easily effected and would result in detonators considerably less prone to impact initiation.

ACKNOWLEDGMENTS

We appreciate the efforts of John A. Brandis in performing the difficult task of disassembling detonators.

TABLE 1. - Data for impacts using the 6.35-cm-diam broad-surface tool--continued

Detonator identification (Key No.)	Remarks	Results at 100-cm drop height	
		Horizontal impact	Vertical impact
	MANUFACTURER 4		
365	Instantaneous EBC, No. 6, plastic case	5 failures	5 failures
9926C	Delay EBC, No. 6, period 3, aluminum case	do.	do.
	MANUFACTURER 5		
280	Instantaneous EBC, No. 6	do.	do.
8005	Fuse type, No. 6, obsolete	4 ignitions, 1 failure	5 ignitions
-	Fuse type, No. 8, obsolete	3 ignitions, 2 failures	5 ignitions
	MANUFACTURER 6		
269	Instantaneous EBC, military item, aluminum case	1 ignition, 4 failures	4 ignitions, 1 failure
	MANUFACTURER 7		
1424A	Instantaneous EBC, foreign product	5 failures	5 failures
1424C	Delay EBC, 80 msec, No. 6 foreign product	do.	do.
	MANUFACTURER 8		
8	Fuse type, foreign product	1 ignition, 4 failures	5 failures

Note: Outer case material is copper or copper alloy unless otherwise indicated.

TABLE 2. - Data obtained from localized impacts on detonators

Detonator identification (Key No.)	Remarks[1/]	Most sensitive region	TIL value (cm)
	MANUFACTURER 1		
1225	Instantaneous EBC, No. 6	Primary	35
1373	Instantaneous EBC, No. 8	Ignition	40
1398B	Delay EBC, 100 msec	Primary	45
1464	Delay EBC, 500 msec, aluminum case	do.	90
1423	Fuse type, No. 6, aluminum case	Ignition - primary[2/]	40
	MANUFACTURER 2		
1297	Instantaneous EBC, No. 6	Ignition - primary[3/]	45
1397C	Delay EBC, 100 msec, No. 8	Delay train	45
1465	Delay EBC, 500 msec, No. 8	Ignition	50
1466	Delay EBC, 2.9 sec, No. 8	do.	50
9000	Fuse type, No. 6	Primary	50
	MANUFACTURER 3		
1099	Instantaneous EBC	Ignition	25
965D	Delay EBC, 175 msec	do.	15
1473	Delay EBC, 500 msec	do.	35
488	Fuse type, No. 6	Ignition - primary[2/]	50
	MANUFACTURER 4		
365	Instantaneous EBC, No. 6, plastic case	Primary	45
9926C	Delay EBC, period 3, No. 6, aluminum case	do.	60

1/ Outer case material is copper or copper alloy unless otherwise indicated.
2/ Separate ignitions and primary charges in such close proximity that both wer impacted simultaneously.
3/ Ignition and primary mixtures combined into single component.

TABLE 2. - Data obtained from localized impacts on detonators--continued

Detonator identification (Key No.)	Remarks[1/]	Most sensitive region	TIL value (cm)
	MANUFACTURER 5		
8005	Fuse type, No. 6, obsolete	Ignition - primary[2/]	25
	MANUFACTURER 6		
269	Instantaneous EBC, aluminum case, military item	Primary	35
	MANUFACTURER 7		
1424A	Instantaneous EBC, No. 6, foreign product	Ignition	25
1424C	Delay EBC, 80 msec, foreign product	do.	25

1/ Outer case material is copper or copper alloy unless otherwise indicated.
2/ Separate ignition and primary charges in such close proximity that both were impacted simultaneously.

TABLE 3. - Friction sensitivities for active components of detonators

Detonator identification	Explosive component	Friction sensitivity (load kg)	
1225; instantaneous EBC, No. 6	Ignition	1.0	
	Primary	< 0.5	(35 cm)*
	Base	2.0	
1464; delay EBC, 500 msec, aluminum case	Ignition	8.0	
	Delay	>36.0	
	Primary	< 0.5	(90 cm)*
	Base	4.0	
1297; instantaneous EBC, No. 6	Ignition - primary	< 0.5	(45 cm)*
	Base	4.0	
1397C; delay EBC, 100 msec, No. 6	Ignition	6.0	
	Delay	1.0	(45 cm)*
	Primary	1.0	
	Base	4.0	
488; fuse type, No. 6	Ignition	0.5	(50 cm)*
	Primary	2.0	
	Base	6.0	
965D; delay EBC, 175 msec	Ignition (1)	0.5	(15 cm)*
	Delay	>36.0	
	Ignition (2)	0.5	
	Primary	1.0	
	Base	4.0	
1473; delay EBC, 500 msec	Ignition (1)	< 0.5	([illegible]5 cm)*
	Delay	-	
	Ignition (2)	-	
	Primary	-	
	Base	2.0	
8005; fuse type, No. 6	Ignition	0.5	(25 cm)*
	Primary	< 0.5	
	Base	24	
269; instantaneous EBC, military item, aluminum case	Ignition	< 0.5	
	Primary	< 0.5	(35 cm)*
	Base	4.0	

*Indicates TIL for impacts on detonator at most sensitive region taken from table 2.

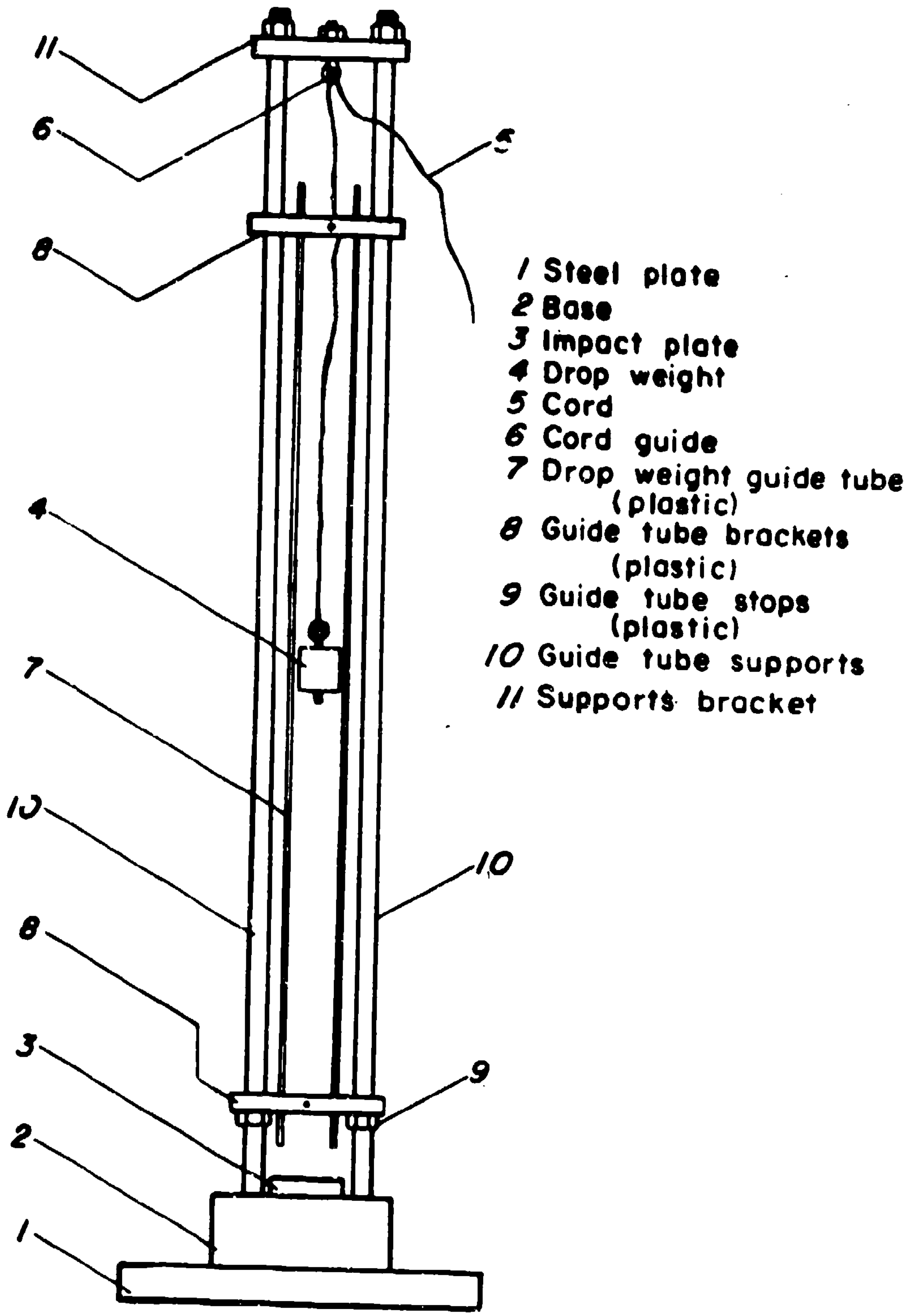

FIGURE 1. - Details of drop-weight tester.

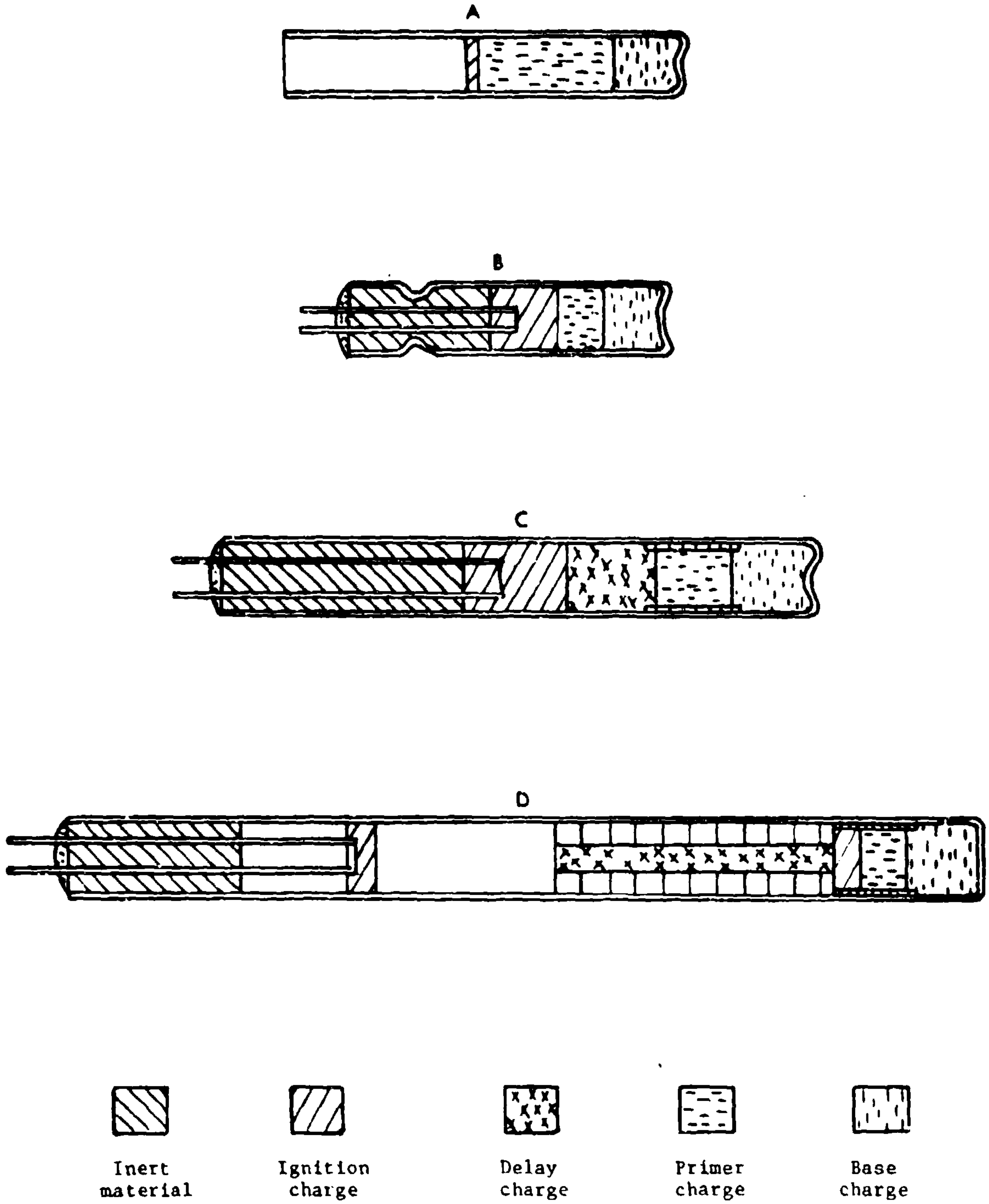

FIGURE 2. - Representative detonator types encountered in detonator impact studies: A, blasting cap; B, instantaneous EBC; C, delay EBC (four active elements); D, delay EBC (five active elements).

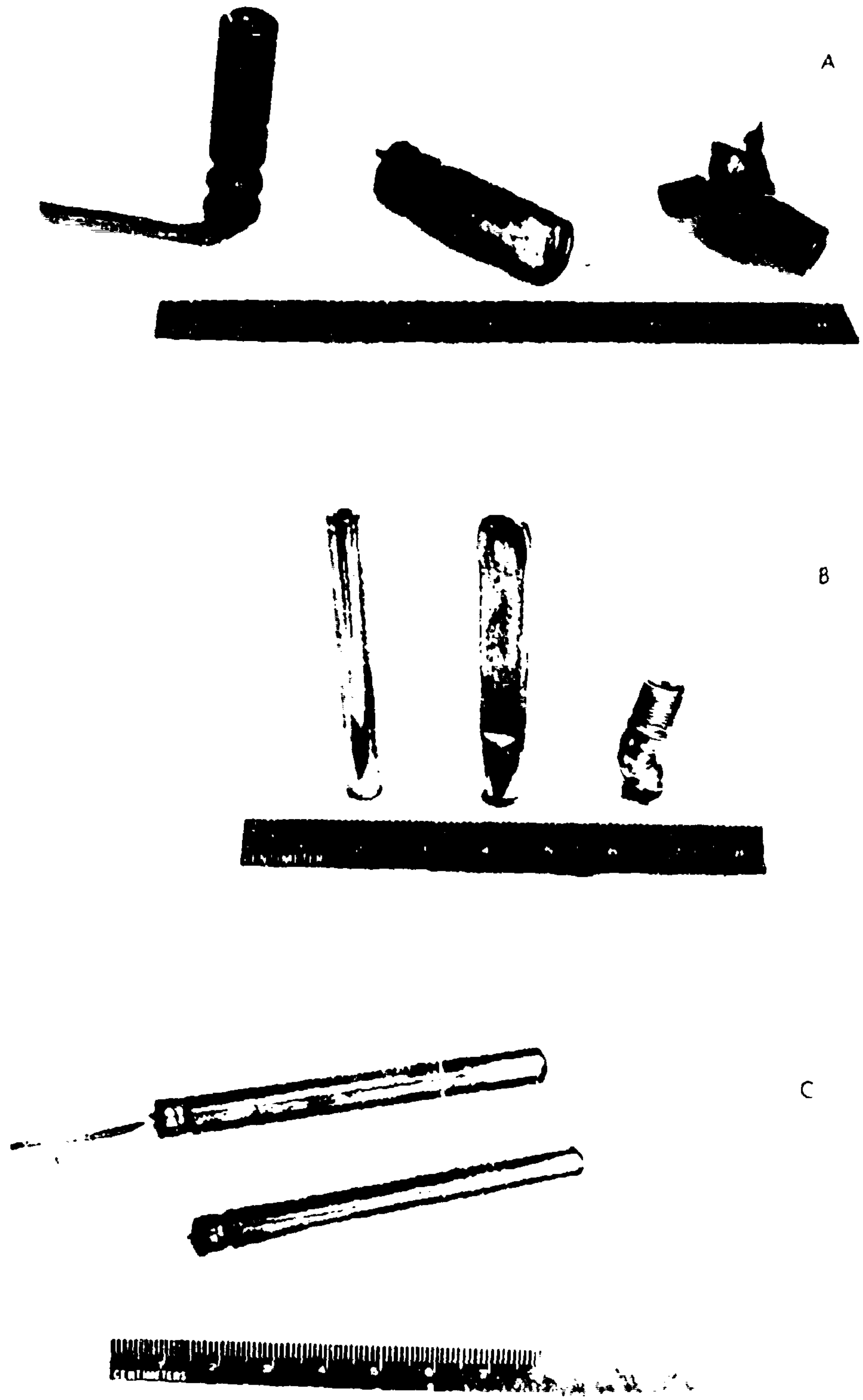

FIGURE 3. - Detonators deformed in horizontal and vertical impacts: A, instantaneous EBC; B, blasting cap; C, delay EBC.

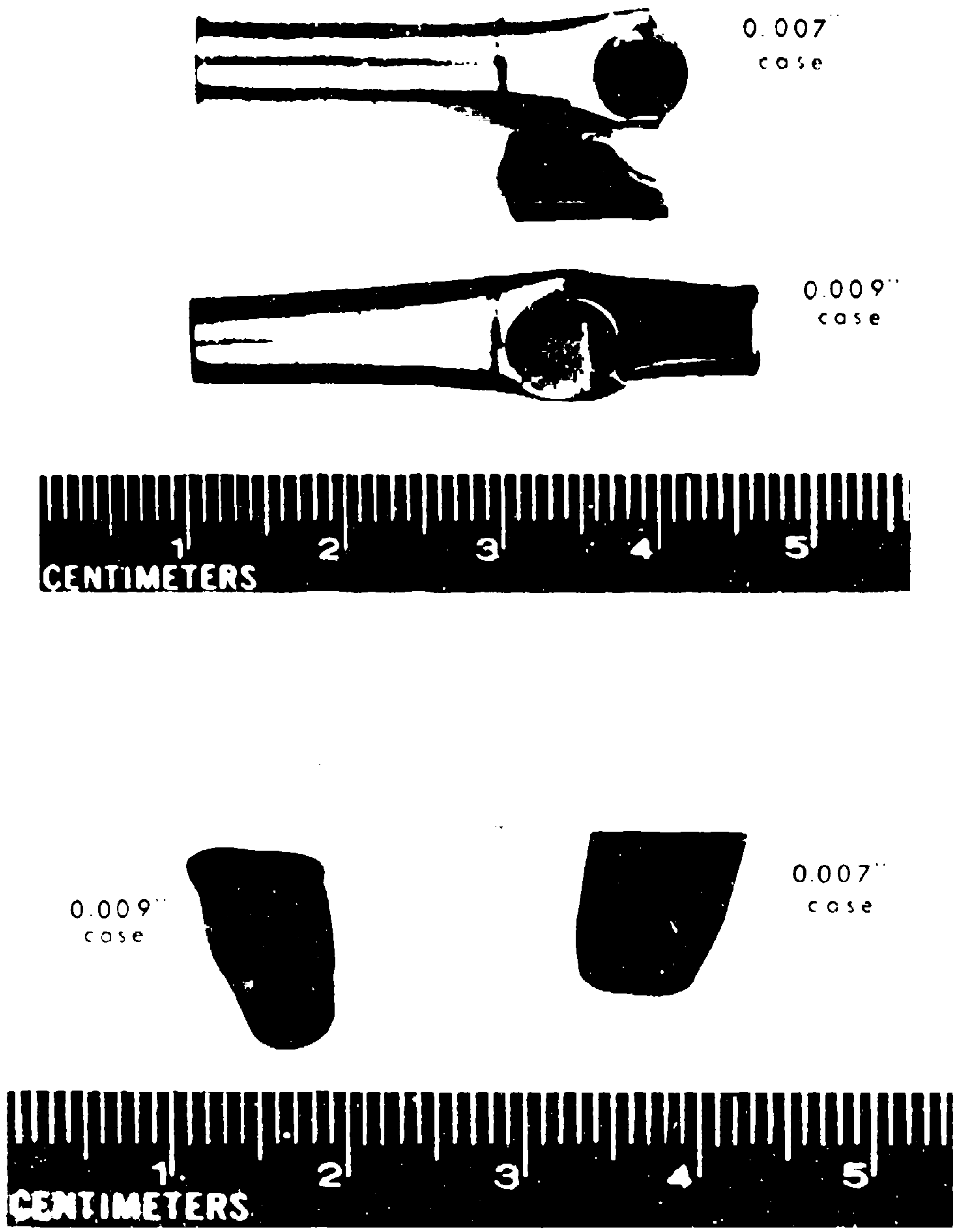

FIGURE 4. - Effect of outer case strength demonstrated by localized impacts on two different live detonators (above) and broad impacts on their empty cases (below).

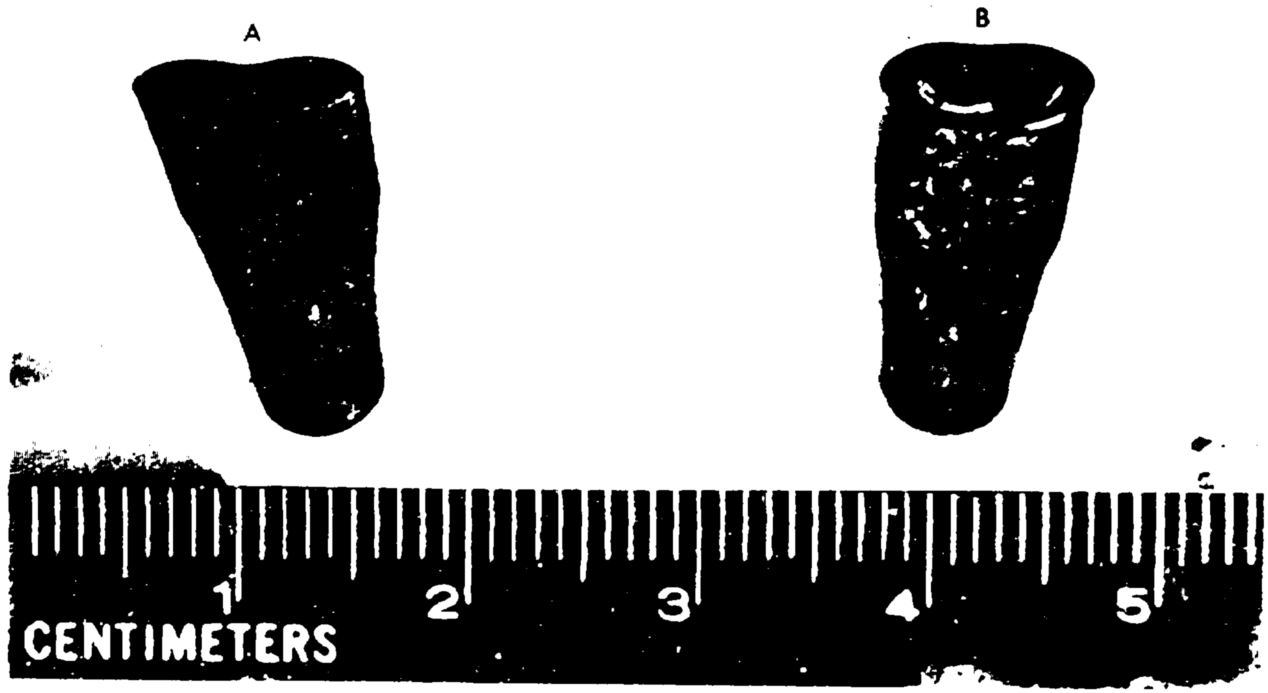

FIGURE 5. - Results of impacts on metal cases of the same detonator type with inner shell removed (A) and with inner shell intact (B).

DECOUPLING OF GROUND SHOCK FROM EXPLOSIONS IN ROCK CAVITIES

by

J. L. Drake
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Miss.

Introduction

Decoupling explosive energy by detonating charges in cavities larger than the charge is an effective method for reducing ground shock magnitudes over those of fully contained bursts. The blasting industry deliberately decouples explosions in presplitting, smooth wall, and cushion blasting operations. This method has been explored as a possible method for concealment of underground nuclear explosions. Decoupling can be an effective means of significantly reducing the energy coupled into the earth by accidental explosions of magazines.

This paper presents an analysis of ground motions produced by decoupled explosions in rock cavities. A simplified elastic solution is used to calculate particle motion magnitudes and time histories produced by an explosion in rock as a function of the initial cavity radius and the loading density of the explosive. Initial cavity conditions were estimated from the adiabatic expansion of the explosive products, and empirical data from decoupling experiments were used to extrapolate initial cavity conditions to low loading densities. This presentation is not intended to be a rigorous solution of the decoupling problem but rather a semi-empirical method which is relatively simple and accurate for estimating ground motions from explosions in cavities.

Elastic Solution

The general solution to the elastic wave equation in spherical coordinates is (see reference 1 for example):

$$u(r,t) = \frac{\partial}{\partial r}\frac{1}{r}F\left(t - \frac{r-a}{c}\right) \qquad (1)$$

where

u = radial particle displacement

r = radial coordinate

t = time

a = initial cavity radius

c = compressional wave speed

$F(\tau)$ is an arbitrary function of the argument $\tau = t - \frac{r-a}{c}$, which is the reduced time. Expressions for particle strain, velocity, stress, etc., can be written directly from equation 1.

Particle velocity is used in this study because it is the most commonly measured and best understood ground motion parameter. It can be determined by differentiation of equation 1 as:

$$v(r,t) = -\frac{1}{r^2}\left[F'(\tau) + \frac{r}{c}F''(\tau)\right] \qquad (2)$$

where a primed notation indicates differentiation with respect to the argument. This expression is an ordinary differential equation which can be easily integrated to determine $F(\tau)$ if the particle motion is specified at some point in the medium. Assuming the particle velocity at the cavity boundary is $v(a,t) = v_0(t)$, then integration of equation 2 gives:

$$F'(t) = -cae^{-ct/a}\int_0^t v_0(\eta)e^{c\eta/a}\,d\eta \qquad (3)$$

Because of the sensitivity of the decoupling phenomenon to the initial cavity radius, it is convenient to integrate equation 3 by parts to obtain a series expansion in powers of the small term (a/c). This procedure greatly simplifies the resulting expressions for estimating particle velocity at large distances. Noting that

$$\int_0^t v_0(\eta)e^{c\eta/a}\,d\eta = \frac{a}{c}\,e^{ct/a}\left[v_0(t) - \left(\frac{a}{c}\right)v_0'(t) + \left(\frac{a}{c}\right)^2 v_0''(t) + \ldots\right] \qquad (4)$$

assuming the medium was initially quiet at $t \le 0$, a formula for particle velocity can easily be found by substituting the series in equation 4 into equations 2 and 3 as:

$$v(r,t) \doteq \left(\frac{a}{r}\right)^2 \left[v_0(\tau) + \frac{r-a}{c} v_0'(\tau) - \frac{a}{c}\frac{r-a}{c} v_0''(\tau) + \ldots\right] \qquad (5)$$

Previous investigations (reference 2) have shown that an input particle velocity function of the form

$$v_0(\tau) = v_0 e^{-\alpha^2\tau^2} \qquad (6)$$

was adequate for describing particle motions from contained explosions. Here it is assumed that the peak particle velocity at the cavity boundary v_0 and the time constant α are functions of the loading density of the explosion. Substituting equation 6 into equation 5 gives:

$$v(r,t) = v_0\left(\frac{a}{r}\right)^2\left[1 + 2\alpha^2 \frac{r-a}{c}\left(\frac{a}{c} - \tau - 2\alpha^2\tau^2\right) + \ldots\right]e^{-\alpha^2\tau^2} \quad ; \tau > 0 \qquad (7)$$

Note that the peak particle velocity occurs at $\tau = 0$, which is the arrival of the wave at radius r and is given by:

$$v_{max} = v_0\left[\frac{a^2}{r^2} + \frac{2\alpha^2 a^2}{c^2}\left(\frac{a}{r}\right) + \ldots\right] \qquad (8)$$

Initial Cavity Conditions

In general, initial cavity conditions, v_0 and α, are functions of the loading density and detonation characteristics of the explosive as well as the elastic constants of the rock. The initial cavity velocity is proportional to the peak gas pressure in the cavity. Assuming that the adiabatic expansion of an ideal gas can be used to estimate the pressure in the decoupled cavity, the peak velocity at the cavity boundary is given by:

$$\frac{v_0(\rho_\ell)}{v_0} = \left(\frac{\rho_\ell}{\rho_0}\right)^\gamma \tag{9}$$

where

$v_0, v_0(\rho_\ell)$ = particle velocity parameters for the fully coupled and decoupled charges, respectively

ρ_0, ρ_ℓ = explosive density and loading density, respectively

γ = ratio of specific heats of the explosion gases

Loading density is defined as the weight of the explosive divided by the cavity volume.

The particle velocity parameter for the fully coupled condition can be estimated from the detonation pressure and the characteristic shock wave impedances of the explosive and rock. The detonation wave in the explosive is partially reflected and partially transmitted by the rock medium. Considering this reflection process to be acoustic, the peak pressure σ in the rock is:

$$\sigma = \rho c v_0 = 2P_e\left[1 + \frac{(\rho c)_e}{(\rho c)_r}\right]^{-1} \tag{10}$$

where

P_e = detonation pressure

$(\rho c)_r, (\rho c)_e$ = characteristic impedances of the rock and explosive, respectively

The impedance of the explosive is taken as the product of the density ρ_0 and the detonation velocity c_e. For most explosives, the detonation pressure can be expressed as:

$$P_e = k\rho_0 c_e^2 \tag{11}$$

where k is a constant less than unity. Combining equation 11 with equation 10, v_0 is given as:

$$\frac{v_0}{c} \approx 2k\,\frac{c_e}{c}\left[1 + \frac{(\rho c)_r}{(\rho c)_e}\right]^{-1} \tag{12}$$

he constant k was determined as

$$k = \frac{3}{8} \tag{13}$$

by comparing equation 8 with experimental peak particle velocity data from fully coupled experiments in granite (reference 3), salt (references 4 and 5), tuff (reference 6), and alluvium (reference 7).

Comparison with Decoupling Experiments

It is convenient to introduce the dimensionless scaled variables

$$\tilde{v}_0 = \frac{v_0}{c} \quad ; \quad \tilde{r} = \frac{r}{a} \quad ; \quad \tilde{\alpha} = \alpha \frac{a}{c} \tag{14}$$

and rewrite the equation for peak particle velocity (equation 8) as:

$$v_{max} = \frac{\tilde{v}_0 c}{\tilde{r}^2} \left(1 + 2\tilde{\alpha}^2\tilde{r} + \ldots\right) \tag{15}$$

This expression was compared with data from decoupling experiments to establish a functional form for $\tilde{\alpha}(\rho_\ell)$ and to verify the dependency of the particle velocity parameter on loading density as given by equation 9.

Relative peak strain and particle velocity data from experiments in granite (reference 8), limestone (reference 8), and both nuclear (reference 9) and conventional (reference 10) explosions in salt are shown in fig. 1 as a function of the relative loading density of the explosive. These data follow equation 9 quite nicely for an overall value of the ratio of specific heats of the explosion gases of 1.2 over a large range of relative density. Considering that several different explosive types (both nuclear and chemical) were used, the scatter in the data is quite acceptable.

The time constant parameter $\tilde{\alpha}$ is difficult to determine with any degree of confidence. Data as reported by the Bureau of Mines (reference 8) were taken from long cylindrical explosives, which adds

uncertainty in the reported periods. Values from the Cowboy experiments (reference 4) suggest that

$$\tilde{\alpha} = 0.08 \left(\frac{\rho_0}{\rho_\ell}\right)^{1/3} \tag{16}$$

which is verified by data from coupled explosions in tuff (reference 6).

Conclusions

A simplified elastic theory is presented for calculating particle motion magnitudes and time histories produced by an explosion in rock as a function of the initial cavity radius and loading density of the explosive. Initial cavity conditions estimated from the adiabatic expansion of the explosive products compared favorably with data obtained from decoupling experiments in three rock types where sources ranged from small high-explosive charges to low-yield nuclear explosions. An average ratio of specific heats of the explosion gases of $\gamma = 1.2$ was found to fit experimental data over a range of loading densities frc 0.05 to 100 percent of the condensed explosive. The scaled time constant was found to vary as the inverse cube root of the relative loading density.

Combining the results of the elastic calculation for peak particle velocity and estimates of coupling effects on initial cavity parameters, a formula for predicting particle velocity magnitudes is found as:

$$v_{max} = v_0 \left(\frac{\rho_\ell}{\rho_0}\right)^{\gamma} \left[\left(\frac{a}{r}\right)^2 + 0.0128 \left(\frac{\rho_0}{\rho_\ell}\right)^{2/3} \left(\frac{a}{r}\right)\right] \tag{17}$$

where v_0 can be calculated from the detonation velocity and initial density of the explosive by the expression given in equation 12. It can be seen that for $\gamma = 1.2$ the peak particle velocity decreases inversely as the cavity radius to the 1.6 power at close ranges and decreases inversely as the cavity radius to the 0.6 power at large distances from the detonation. The $1/r$ term becomes more dominant for low relative values of the loading density.

The predicted particle velocity time history has an abrupt rise followed by an exponentially decaying pulse which has a positive duration of:

$$\tau_{+} = \frac{c}{2\alpha^{2} r} + \frac{a}{c} = \frac{a}{c}\left[1 + 78\left(\frac{\rho_{\ell}}{\rho_{0}}\right)^{2/3}\left(\frac{a}{r}\right)\right] \qquad (18)$$

which has a component due to the cavity size and a second term which decreases with range and is independent of the initial cavity radius. This result is verified by the Cowboy (reference 4) and Sterling (reference 9) decoupling experiments in salt where decoupled periods decreased to the value of a/c . A rise time can be added to the predicted pulse without difficulty. It is shown in reference 1 that the rise time parameter for fully coupled charges is dependent upon the rock jointing patterns and is independent of the explosive size.

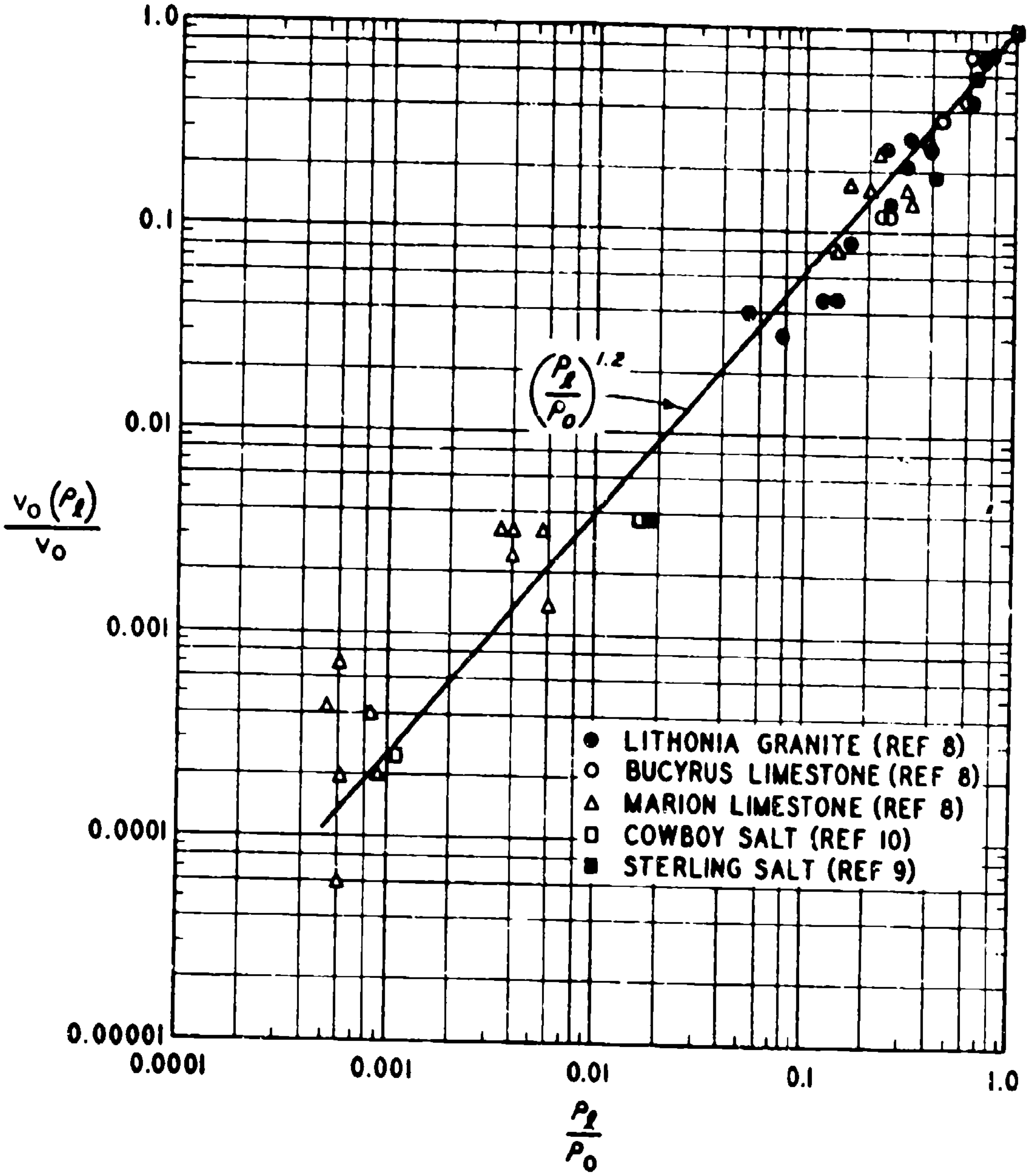

Figure 1. Relative peak particle velocity versus relative loading density

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MODELING DISTRIBUTED EXPLOSIVE CHARGE EFFECTS IN ROCK AND SOIL

H.F. Korman*

1. INTRODUCTION

In recent years buried distributed explosive charges have been used to simulate ground motions resulting from effects originating inside the crater region due to a nuclear weapon detonation. Semi-empirical techniques have been developed to predict the simulation environments and applied to optimize the design of the charge arrays (e.g., Reference 1). One technique is described herein which was developed for predictions for rock media (Reference 2) but has also been applied to soil media predictions (Reference 3). Although developed for application toward hardened structures it is general enough for broader civil engineering application. As a result of the empirical basis for the technique, improvements can be easily incorporated as more data become available and broader usage is imposed. The good agreement between limited test data and predictions in a rock material encourages its further development and application.

In Section 2 the prediction model is described in detail. Section 3 compares calculations with test data in rock obtained using a buried planar array of explosive columns (Reference 2). A parametric investigation of ground shock in soil for planar and circular arc shaped charge arrays (Reference 3) is presented in Section 4. To conclude this paper an overview of its basis, required inputs, and output display which demonstrates the ease for modification is displayed in Section 5. The application of the model to coal mine safety is also outlined.

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*Member of the Technical Staff, TRW Systems Group, Redondo Beach, California.

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2. MODEL DESCRIPTION

The model for calculating the free field response due to an array of buried explosive charges, described in this section, has been synthesized into the DIstributed Buried Charge SIMulation (DISIM) code. Available data for the free field response due to single charges of contained high explosives are the basis for DISIM. The expressions for peak values of displacement, velocity and acceleration are based on empirical fits to underground detonation data (Reference 4), while the waveform shape was adjusted to match single charge measurements (Reference 5). Superposition is used to add up the vector components of the free field motion history created by each charge in an array. Even though the response is nonlinear, superposition of responses to individual charges was found to give reasonable results. This is partly due to the fact that the stress levels are significantly attenuated at the response points of interest.

If a line charge of explosive slurry is to be simulated, the line is represented by a series of single charges generally corresponding to the number of detonators in the line. DISIM computes and sums the responses produced by each equivalent point charge, considering the appropriate time of arrival phasing.

For each individual charge input to the code DISIM uses the following empirical relationships for peak values of radial displacement, velocity, and acceleration

$$D = 0.42 \left(\frac{W}{\text{lbs}}\right)^{0.87} \left(\frac{r_i}{\text{ft}}\right)^{-1.6} \quad \text{in} \tag{1}$$

$$V = 400 \left(\frac{W}{\text{lbs}}\right)^{0.6} \left(\frac{r_i}{\text{ft}}\right)^{-1.8} \left(\frac{c_p}{6000\ \text{fps}}\right) \quad \frac{\text{in}}{\text{sec}} \tag{2}$$

$$A = 6.95 \times 10^{6} \left(\frac{W}{\text{lbs}}\right)^{0.33} \left(\frac{r_i}{\text{ft}}\right)^{-2} \left(\frac{c_p}{6000\ \text{fps}}\right)^{2} \quad \frac{\text{in}}{\text{sec}^2} \tag{3}$$

where W is the charge yield for each source measured in pounds (lbs) of TNT, r_i is the radial distance between the charge location and the test point measured, and c_p is the P-wave speed of the medium. (The code was developed initially for rock media, and subsequently the peak waveform parameter expressions of the program were modified by introducing seismic speed scaling (Reference 6) reflected in the above equations for application to general homogeneous soil media.)

The corresponding waveform, as shown in Figure 1, is defined by the following analytical expressions:

$$v(t) = \begin{cases} 0 & t \leq 0 \\ At & 0 \leq t \leq t_1 \\ V\left(\frac{t_2 - t}{t_2 - t_1}\right) \exp\left\{-\beta\left(\frac{t - t_1}{t_2 - t_1}\right)\right\} & t_1 \leq t \leq t_2 \\ -\frac{V}{10}\left(\frac{t - t_2}{t_3 - t_2}\right) & t_2 \leq t \leq t_3 \\ -\frac{V}{10}\left(\frac{t_4 - t}{t_4 - t_3}\right) & t_3 \leq t \leq t_4 \\ 0 & t_4 \leq t \end{cases} \tag{4}$$

where

$$t = \tau - \frac{r_i}{c_p}$$

$$t_1 = \frac{V}{A}$$

$$t_2 = \frac{5D}{V}$$

$$t_3 = \frac{9D}{V}$$

$$t_4 = \frac{13D}{V}$$

and τ is the time measured from the DIHEST detonation. (Note that this definition of τ permits the introduction of a time lag for introducing time phasing effects). The exponential coefficient β represents the fact that the particle displacement reaches maximum value at t_2 because $v(t_2) = 0$, and has a value of 3.76 for the constants in Equations (1) through (4).

The DISIM program considers both the environment due to the initial compressive wave, described by Equations (1) through (4), and to the wave generated from the free surface reflection of the initial wave. The reflected P-wave is handled by considering a virtual charge source located at the image point of the real source with respect to the ground surface. An attenuation factor is applied to the virtual source to account for the energy lost to the shear wave (S-wave) in the reflection from the free surface. DISIM does not include the effects of the reflected S-wave, as it is assumed to attenuate much faster than the P-wave component.

For each virtual charge, the peak motion parameters of Equations (1) through (3) are multiplied by an attenuation factor δ (Reference 7) defined as

$$\delta = \left| \frac{\tan \alpha \cos 2\gamma - 2 \sin^2 \gamma \tan \alpha}{\tan \alpha \cos 2\gamma + 2 \sin^2 \gamma \tan \alpha} \right| \tag{5}$$

where

$$\sin \gamma = \sqrt{\frac{1-\nu}{2(1-\nu)}} \tan \alpha$$

α is the angle between the incident P-wave and the vertical direction, ν is Poisson's ratio for the medium, and γ is the reflected S-wave angle. The absolute value of the expression in Equation (5) is taken since the actual value can be negative, which represents a change of phase upon reflection. For calculations discussed below ν = 0.2 was used for rock, while 0.3 was used for soil.

3. COMPARISON WITH TEST DATA FOR ROCK

DISIM was used to predict the ground motions in rock associated with the DATEX II event (Reference 2). The technique used in this event for developing the shock environment using a buried array of explosive columns

is called the Direct Induced High Explosive Simulation Technique (DIHEST). Normally, each shot hole may contain canisters of ammonium nitrate positioned at various depths or a slurry explosive with detonators positioned along its length (See Figure 2). The depth and width of the array, the spacing of shot holes, the spacing of detonators, the degree of containment, the charge weight and the detonation time phasing are the variables which govern the induced ground motion. The results of the calculation as well as the measured data are presented in this section for horizontal velocity and displacement (hereafter referred to as velocity and displacement) along the vertical mid-plane of the explosive matrix.

The DATEX II explosive matrix was composed of twenty-nine coplanar vertical shot holes which were spaced at 7.2 ft centers. Each shot hole had 40 ft of IRECO DBA-X2M slurry explosive which was capped by 25 ft of grout. Each column of explosive slurry had 5 detonators spaced 8 ft apart and a charge weight of about 2840 lbs resulting in a total charge weight of 82000 pounds for the array.

The DATEX II input values for DISIM calculations are shown in the table of Figure 2. Each detonator represents a single source of explosive with a charge weight of 568 pounds. Results were calculated for points where measurements were made in the field. Velocity was typically measured at depths of 4, 16, and 40 ft and ranges from 50 to 200 ft.

Figure 3 summarizes the measured and calculated peak velocities (V) as a function of range (X) and depth (Z). As can be seen in the plot of all points, all of the calculations are within the scatter of all the measured data.

Further examination of the results in Figure 3 show very good agreement between the measured and calculated peak velocity at depths of 4 and 16 ft. Calculated peak velocities at 40 ft were generally about a factor of two higher than the measured peak velocities. A possible reason for the lower velocities at greater depth is the existence of a harder formation of rock at depths greater than 30 ft. The effects of a layered media were not considered in the DISIM calculations. Range attenuation agreement is very good at all depths, with the measured and calculated attenuation rates being closely approximated by $X^{-1.8}$

Although complete agreement of DISIM and measured velocity waveforms was not expected, their comparisons were encouraging. Figure 4 shows a comparison of two velocity waveforms at measurement points (X, O, Z) located at (145,0,4) and (185,0,40). In both cases, the velocity and displacement waveforms show reasonable agreement. The shape of the measured velocity waveform in Figure 4 suggests that the peak velocity may have been cut off because of gage saturation. Agreement of the wave prior to and after the peak cut off is very good. The measured velocity pulse shows a smaller attenuation rate after the peak values. This caused the predictions of peak displacement to be generally lower than the measured displacements which are obtained by integrating the velocity records. Figure 5, which summarizes the measured and calculated peak displacements, shows that the calculations are within the scatter of the measured data.

It should be noted that the preceding comparison of DISIM calculations with the measured field data is for one of several DIHEST events in similar

geologic media. Although there are differences among various other test events in array geometry, charge weight, and type of explosive, DISIM calculations for those events compared equally well with the measured data, and the trend observed in DATEX II was also seen in those events. Modification of DISIM to include layering of the media should provide a noticeable improvement in the agreement of depth attenuation. Displacement can be enhanced by modifying the empirically fitted velocity pulse defined by Equation (4).

4. PARAMETRIC INVESTIGATION OF GROUND SHOCK IN SOIL

For this investigation a number of DIHEST configurations based upon the one shown in Figure 2 were studied in a soil media. The choice of depth of burial for the top of the charge columns was based on minimizing cratering effects. Although a shot hole diameter of 13 inches and explosive slurry (IRECO DBA-X2M) was considered in this study, the results generally apply to any type of explosive that gives the same combination of average charge density distribution and efficiency in the surface containing the array. The energy contained in each charge column was assumed to be concentrated at, and evenly divided among, the detonators.

The primary purpose in simulating the DIHEST environment was to obtain suitable peak displacements without incurring unreasonably large velocities. Early results indicated that a charge weight of 100 tons would not be satisfactory, hence this study concentrated largely on optimizing the response for a 250 ton total charge weight.

In order to investigate the DIHEST phenomena more completely, both uniformly and nonuniformly spaced charge columns are considered. In addition, charge columns placed on a circular arc in plan view were also considered. Both configurations are shown in Figure 6. The nonuniformly spaced arrays considered the middle-third charge columns to have a uniform spacing and each outside-third group of charge columns also to have a uniform spacing, which is different from that of the middle-third.

Table I summarizes the thirteen DIHEST cases considered in this study. The first three cases considered total charge weights of 250 tons with only the horizontal spacing between charge columns varied between cases. The fourth case considered charge columns twice as long as did the second case, but the spacing between columns was doubled and the average charge density within the surface of the array was the same for both cases. The fifth case was also a variation of the second case with the P-wave speed of the medium being reduced froom 3000 fps to 2000 fps to study site geology effects. The sixth and seventh cases considered different total charge weights. Cases 8 and 9 were again variations of Case 2. They considered the same charge spacing but the charge columns were placed on circular arcs as indicated in Figure 6. The remaining cases considered nonuniformly spaced charge lines. In each case a two-to-one or one-to-two ratio between the spacing within the inside and outside groups of columns was considered.

Horizontal motion responses were computed at ranges of 75, 150, 300 and 600 ft and at a depth of 50 ft. Figure 7 shows the velocity time histories for two ranges of Case 2. Since a primary objective of this study was to maximize the displacement within a specified peak velocity, the results are

presented in terms of peak velocity versus peak displacement curves with the response range as a parameter.

Figure 8 shows a comparison between the peak horizontal velocity-peak horizontal displacement responses for a 250 ton charge array with charge spacings of 3 ft, 6 ft, and 12 ft. The corresponding array widths are 510 ft, 1020 ft and 2040 ft, respectively. An envelope of these response curves is also shown in the figure. It represents the peak displacements that could be obtained from a 250 ton uniformly spaced array for specified peak allowable velocities.

It is seen that the larger the allowable peak velocity, the more closely spaced is the optimum array. Figure 9 shows a plot of the optimum charge column spacing versus the allowable peak velocity. This optimum spacing is only approximate because of the limited number of column spacing cases which were studied. Also shown on the figure is the peak displacement curve associated with the optimum array.

The second and fourth cases considered the responses for two different arrays such that the average charge density along the array width was equal for both cases. The responses for both cases were nearly equal at all ranges. Thus, as would be expected, a localized rearrangement of the charges does not influence the response.

It is seen in Figure 10, where the effect of varying the medium P-wave speed is displayed, that the displacements at corresponding ranges for both media are about equal and that the velocities are reduced by approximately the

ratio of the P-wave speeds. Thus, the peak displacement increases from 4.5 to 6.0 inches for a peak velocity of 60 ips when the softer medium is considered. A comparison of these results points out that the softer sites are more desirable from a DIHEST standpoint.

Figure 11, which compares the results of Cases 2, 6 and 7, shows the effect of variations in total charge weight. However, these results can be used to develop only approximate yield scaling relations since only a nominal attempt was made to use the optimum charge line spacing in Cases 6 and 7. It is seen that a rather small increase in peak displacement is obtained when the charge yield is doubled.

An approximate relationship can be developed for the peak displacement that can be obtained from a uniformly spaced array of charge columns. On the basis of the results of Cases 1 through 7 the peak displacement relationship is

$$d_m = 0.40 \left(\frac{v_m}{c_p}\right)^{0.81} \left(\frac{W}{250}\right)^{0.20} \quad \text{in} \qquad (6)$$

where v_m is the peak allowable velocity in ips, c_p is the P-wave speed of the medium in kfps, and W is the total charge weight in tons. Until further calculations are performed, the applicability of Equation (6) to the range outside of this parametric study is questionable.

The remaining cases of Table I were variations of Case 2 which considered nonuniform spacing and a circular arrangement of the charge columns. The results are shown in Figures 12 and 13. The circular arc array comparison of Figure 12 indicates that placing the columns on a 750 ft radius gives the best

displacement response. However, the increase in displacement over the planar array case may not be worth the effort and cost of placing the columns on circular arcs.

In Figure 13 the four nonuniformly spaced array responses are compared with the envelope of the optimum response that could be obtained from uniformly spaced arrays. It is seen that in the regions between 70 and 180 ips and below 40 ips, the optimum response is obtained with nonuniformly spaced arrays.

5. CONCLUSIONS

Figure 14 summarizes the DISIM methodology. Using the peak parameter, depth attenuation, and waveform data base, calculations are performed for a specific seismic profile and buried charge configuration. The results can be displayed in terms of peak motion variables, wavefore shape, shock spectra, or parametric sensitivity figures.

Although DISIM has been used primarily for ground motion predictions associated with DIHEST test events, it is applicable to the study of the free field ground shock phenomena associated with any array of buried explosives. A particular application of interest relates to coal mine safety. In order to predict safe separation distances between underground mines or mines and stripping operations to eliminate blast damage in the underground coal mine, free field ground shock computations can be combined with cavity response calculations. These would be used to study effects due to site properties, mine configuration, and explosive array parameters. When a mining operation is being contemplated, a parametric study could be performed to optimize the

rock blasting free field shock environment subject to charge array, mine configuration, and safety constraints. Parameters such as

- charge size
- charge pattern (rectangular vs. arc shaped, slanted vs. vertical, etc.)
- charge depth
- charge array aspect ratio
- detonation time phasing

could be varied in the tradeoff study. Thus the DISIM methodology is versatile enough to have application in other civil engineering areas.

ACKNOWLEDGEMENTS

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Table I. Summary of Parametric Cases for Ground Shock in Soil*

a) Uniformly Spaced Charge Lines

Case	W (tons)	C_p (fps)	r (ft)	NL	NC	B (ft)	Comments
1	250	3000	3	171	5	510	
2	250	3000	6	171	5	1020	
3	250	3000	12	171	5	2040	
4	250	3000	12	87	10	1028	
5	250	2000	6	171	5	1020	
6	500	3000	3	341	5	1020	
7	100	3000	7.2	69	5	490	
8	250	3000	6	171	5	1020	Placed on 750' Radius
9	250	3000	6	171	5	1020	Placed on 1750' Radius

b) Nonuniformly Spaced Charge Lines

Case	W (tons)	C_p (fps)	XRI (ft)	XRO (ft)	NLI	NLO	NC	B (ft)
10	250	3000	6	3	57	57	5	678
11	250	3000	6	12	57	57	5	1704
12	250	3000	3	6	57	57	5	852
13	250	3000	12	6	57	57	5	1356

*See Figures 2 and 6 for definition of terms.
In all cases, d = 25 ft., S = 8 ft.

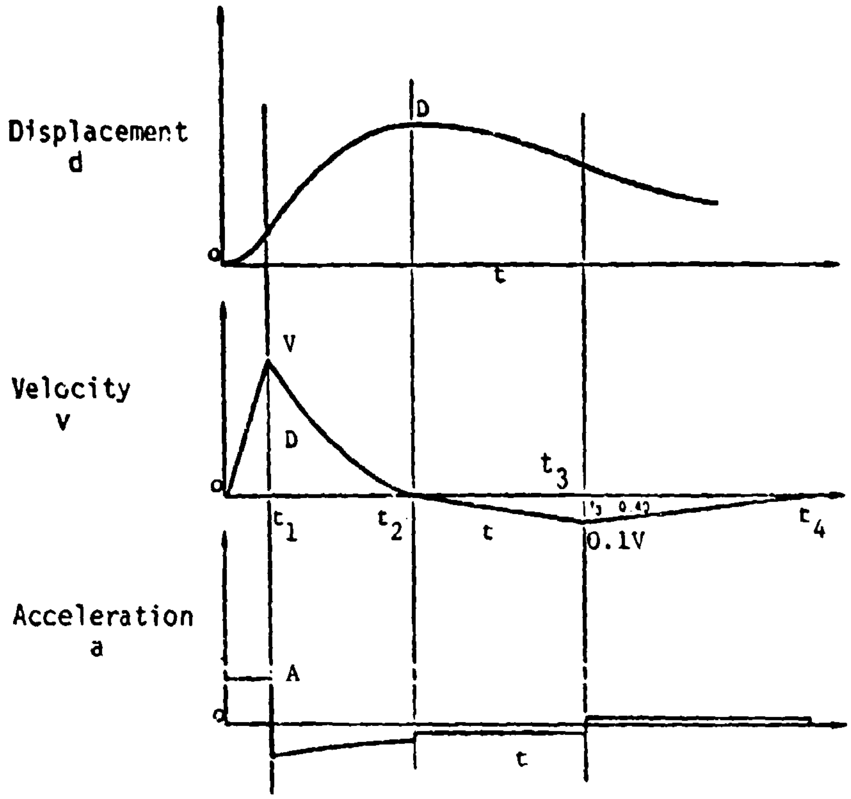
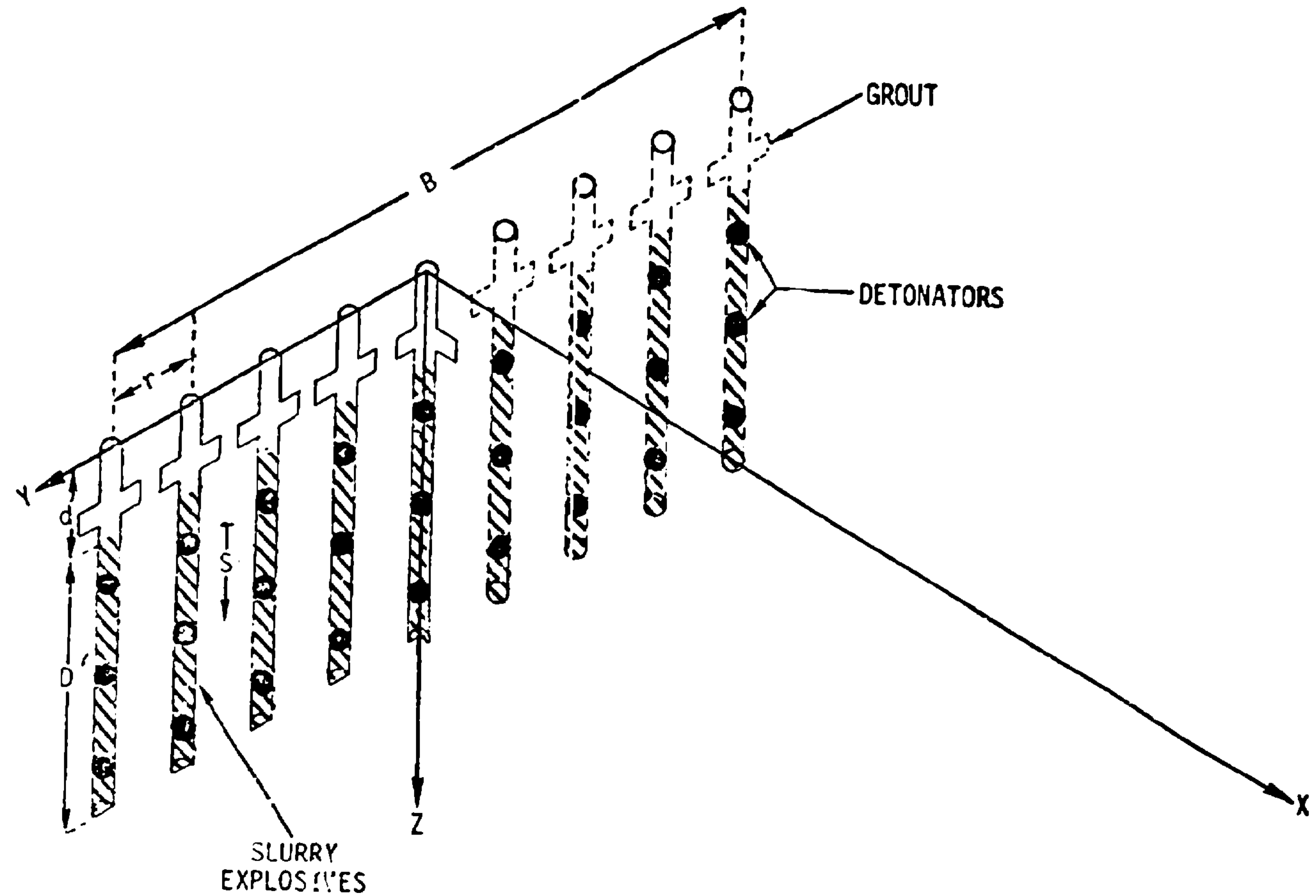


FIGURE 1. TYPICAL DISIM INPUT WAVEFORMS



DATEX II	r (ft)	S (ft)	B (ft)	D′ (ft)	d (ft)	Number of Holes, NL	Detonators Per Hole, NC
INPUTS	7.2	8	202	40	25	29	5

FIGURE 2. EXPLOSIVE ARRAY AND DATEX II SIMULATION VALUES

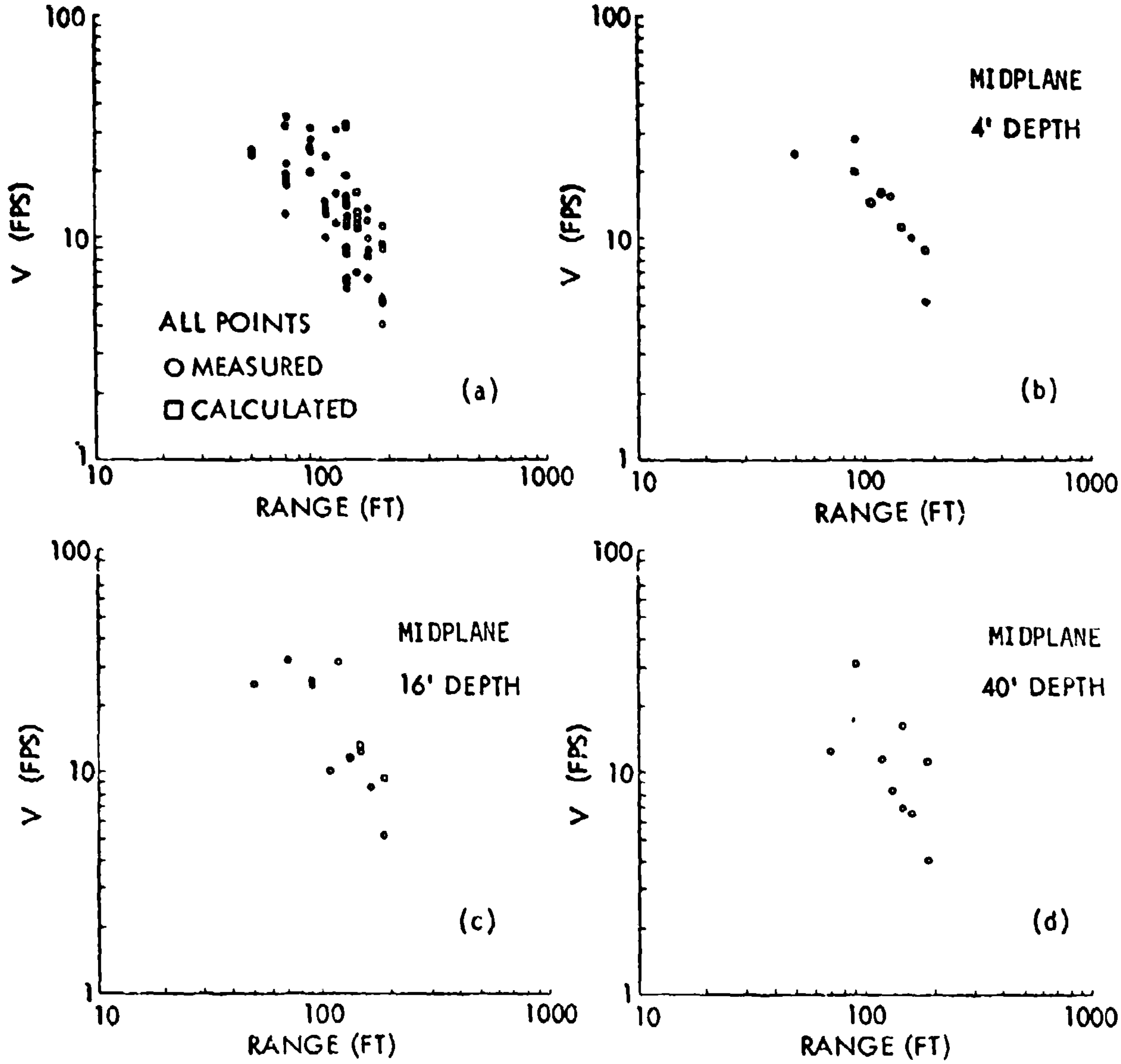


FIGURE 3. DATEX II HORIZONTAL VELOCITY

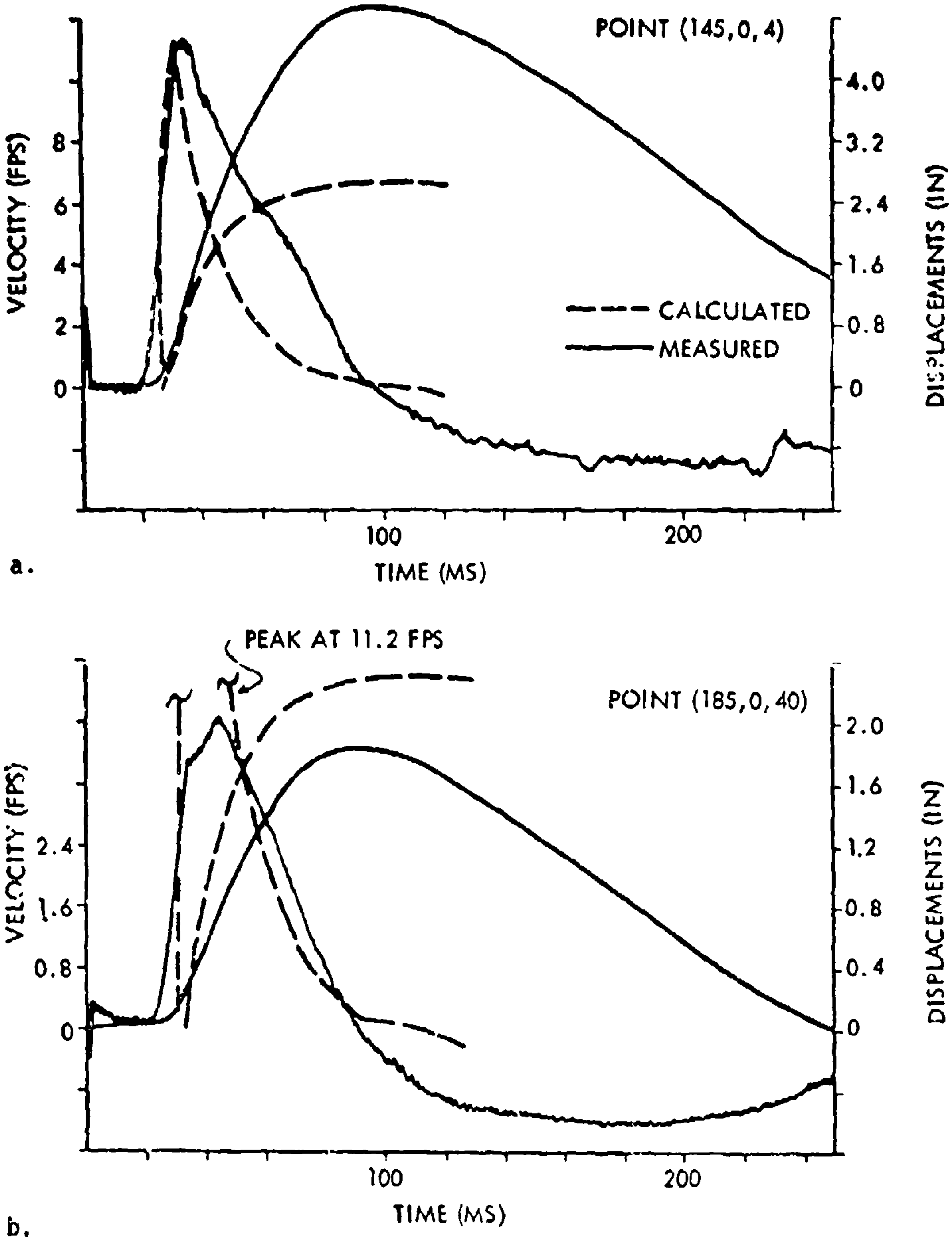


FIGURE 4. DATEX II TEST/ANALYSIS WAVEFORM COMPARISONS

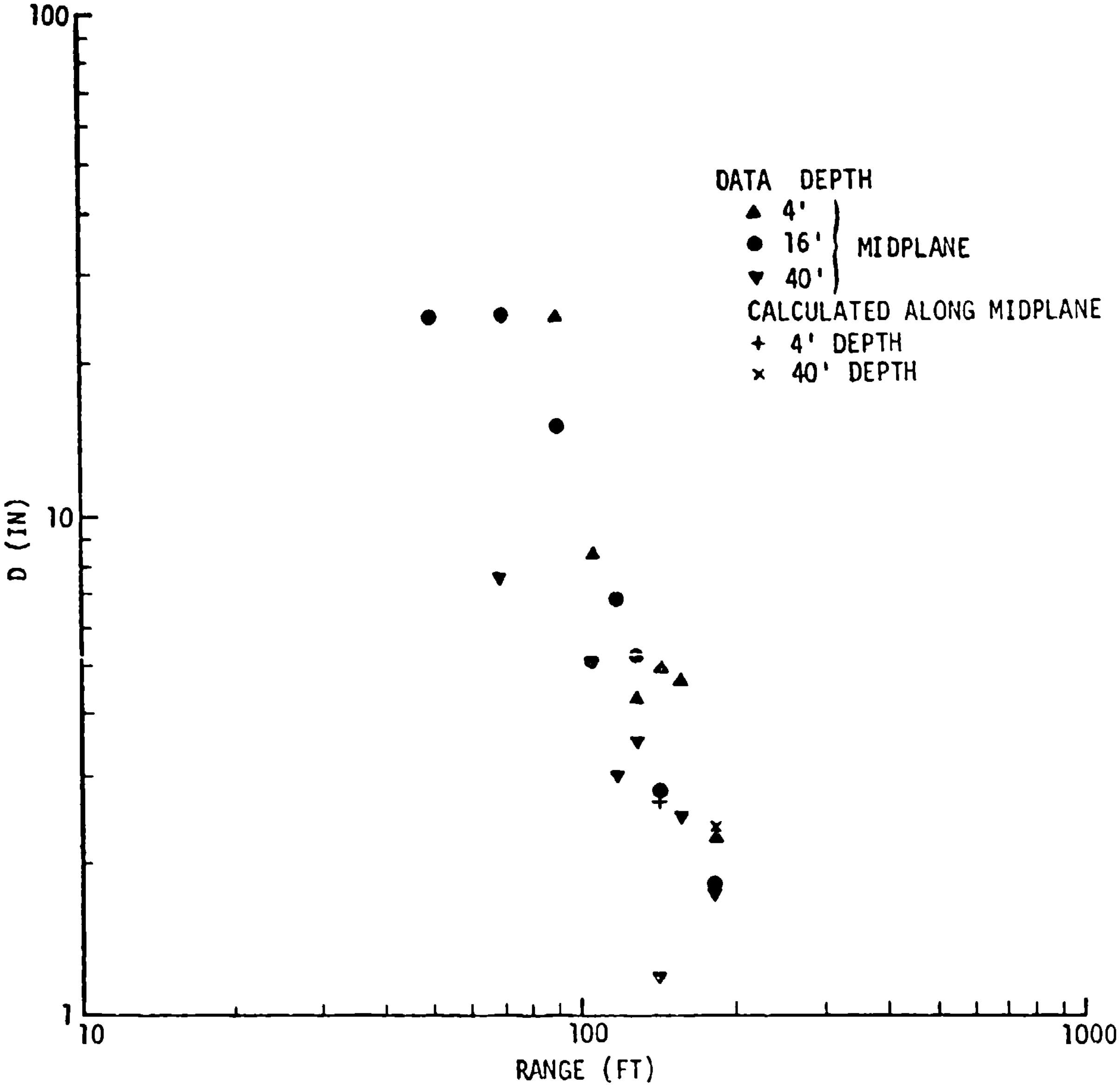


FIGURE 5. DATEX II HORIZONTAL DISPLACEMENT

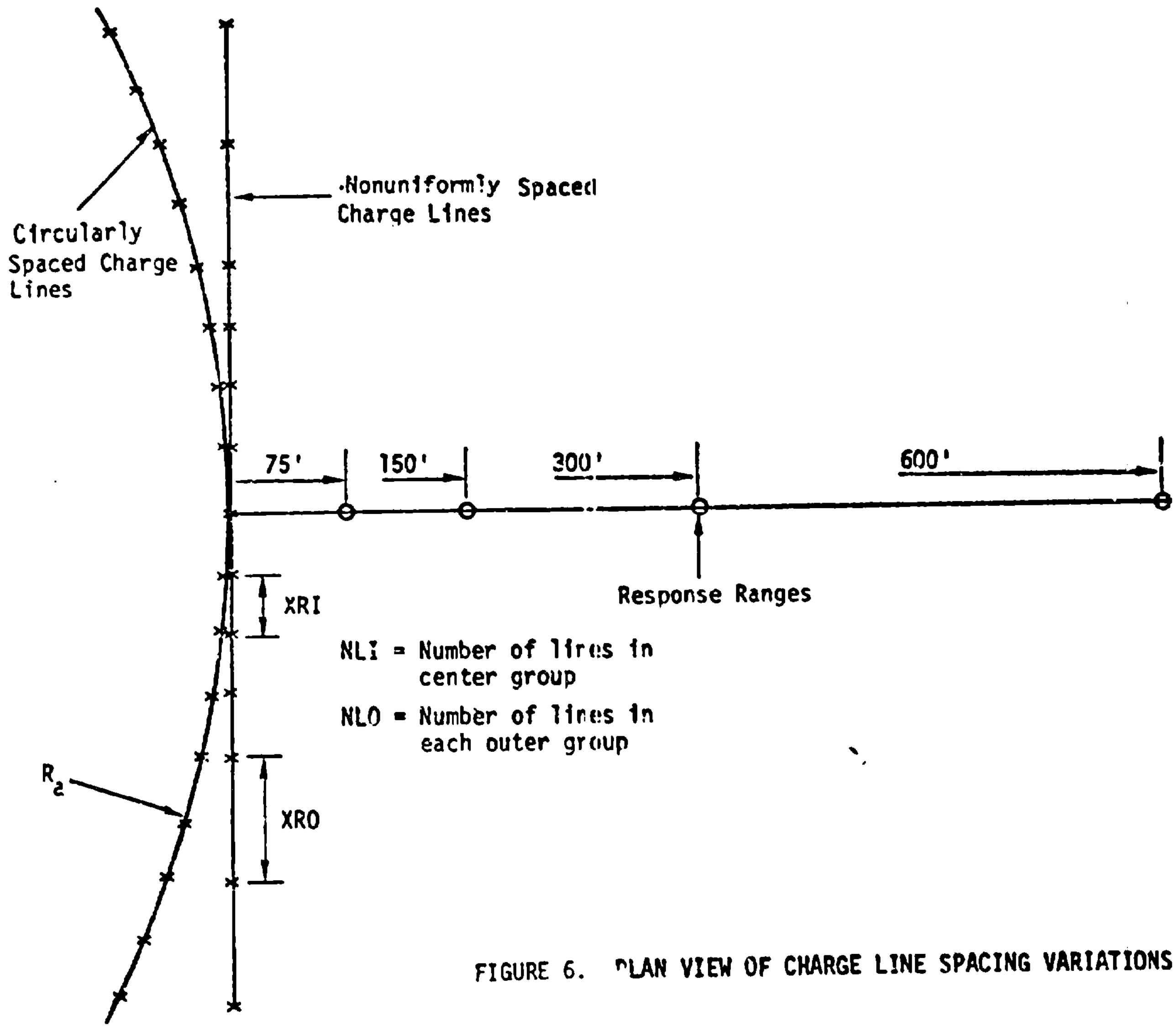


FIGURE 6. PLAN VIEW OF CHARGE LINE SPACING VARIATIONS

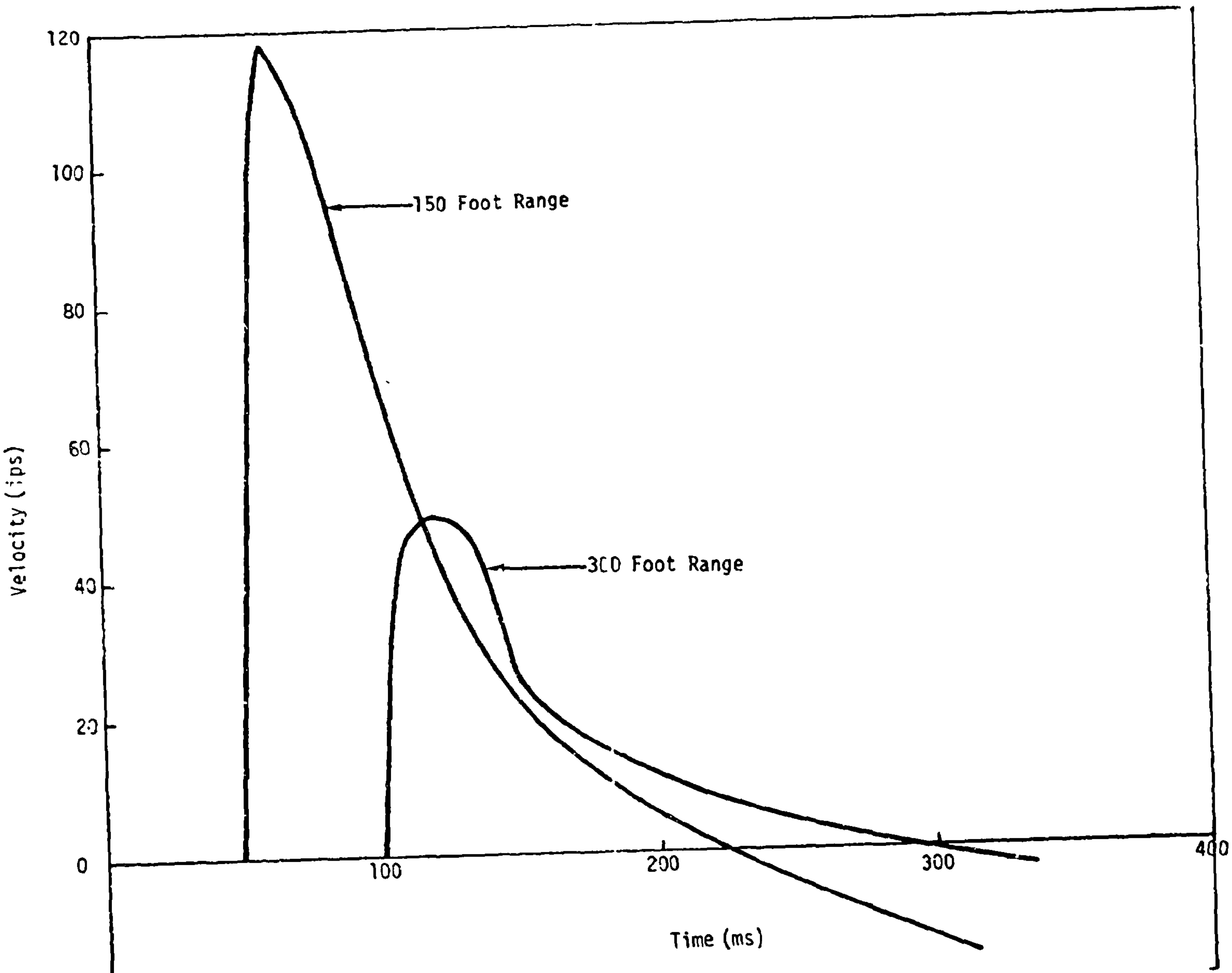


FIGURE 7. VELOCITY TIME HISTORIES AT 50 FOOT DEPTH (CASE 2)

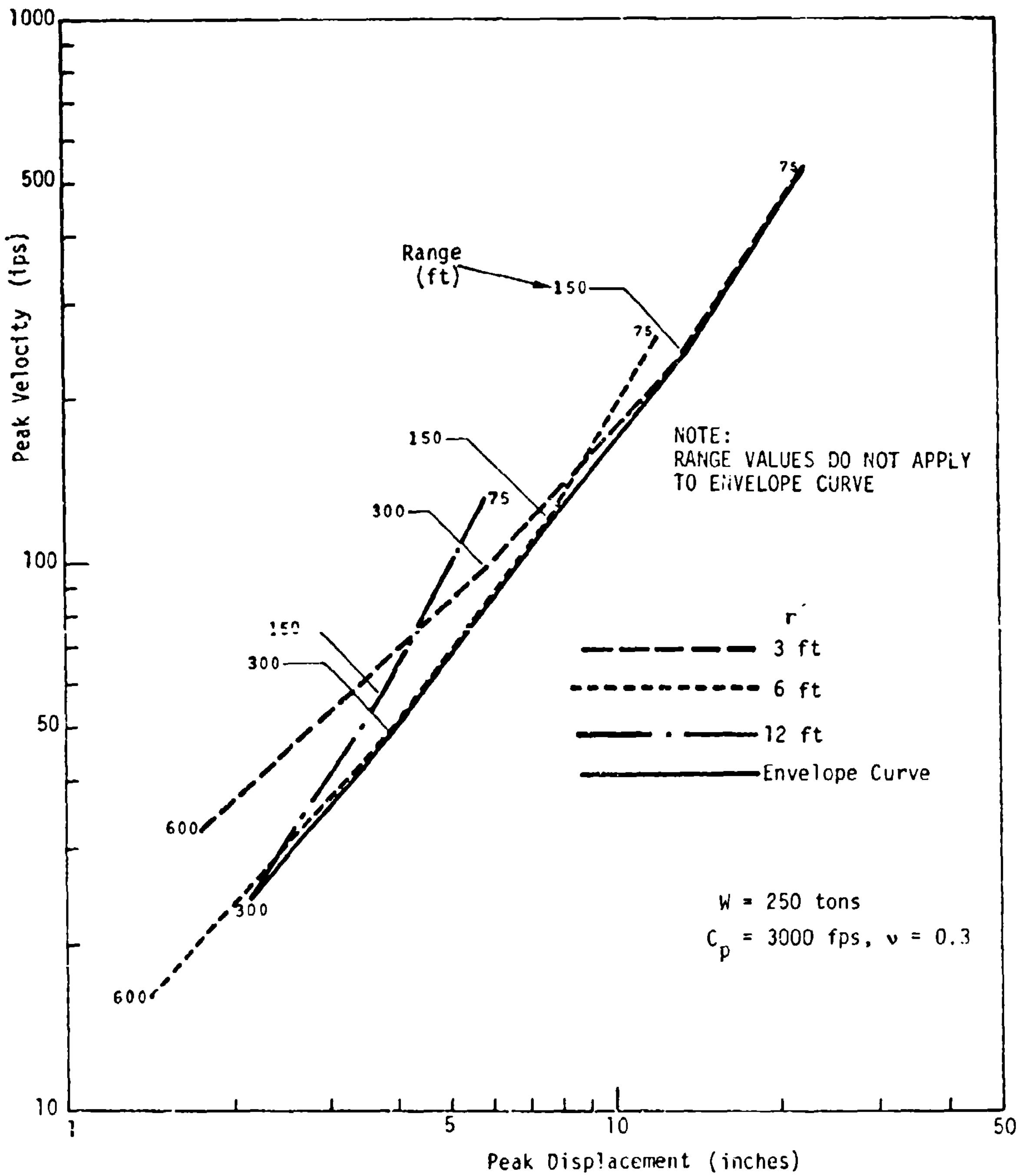


FIGURE 8. VARIATION OF DIHEST ENVIRONMENT WITH HORIZONTAL SPACING BETWEEN CHARGE LINES

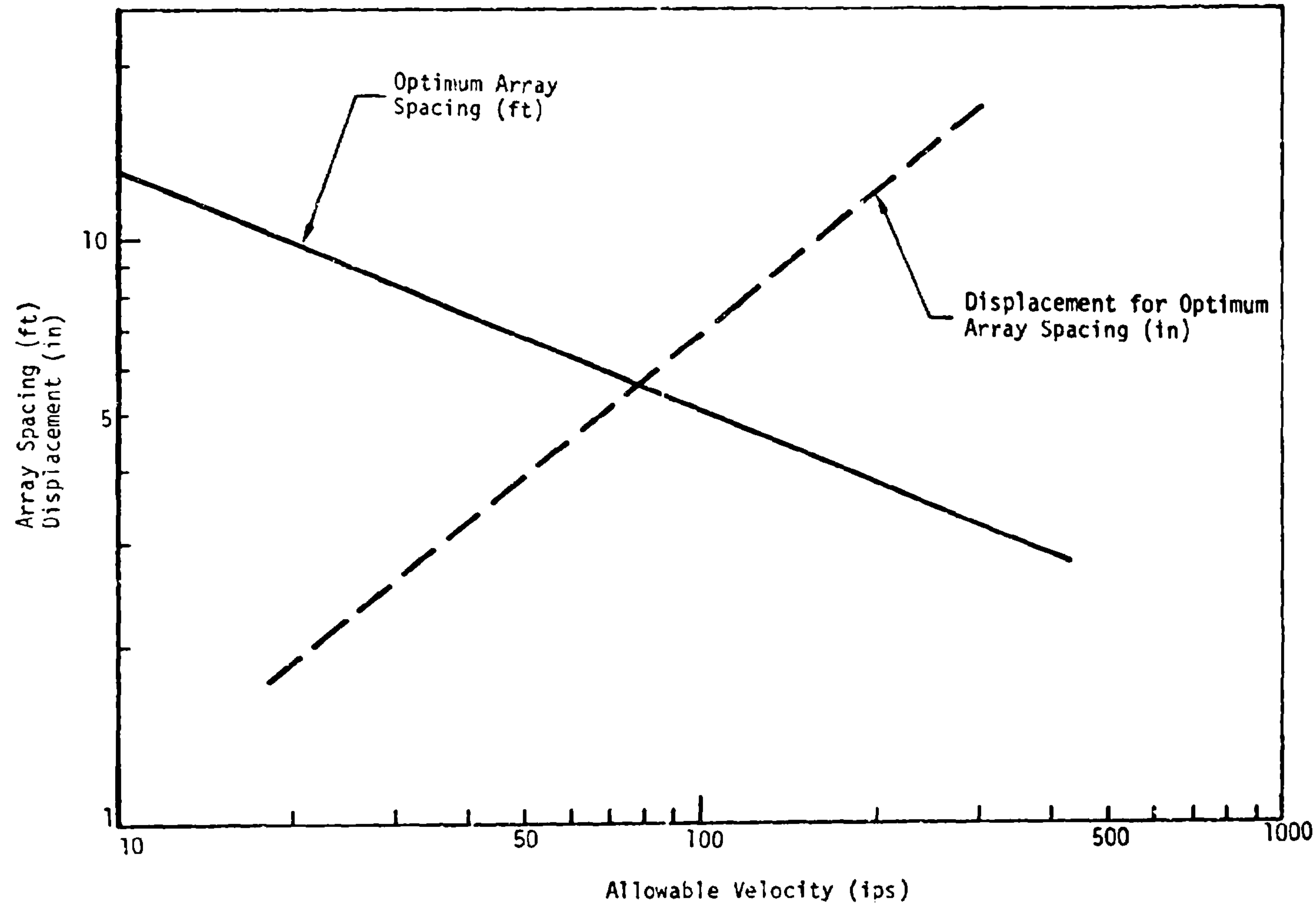


FIGURE 9. OPTIMUM UNIFORM ARRAY SPACING TO ACHIEVE MAXIMUM DISPLACEMENT WITH SPECIFIED ALLOWABLE VELOCITY

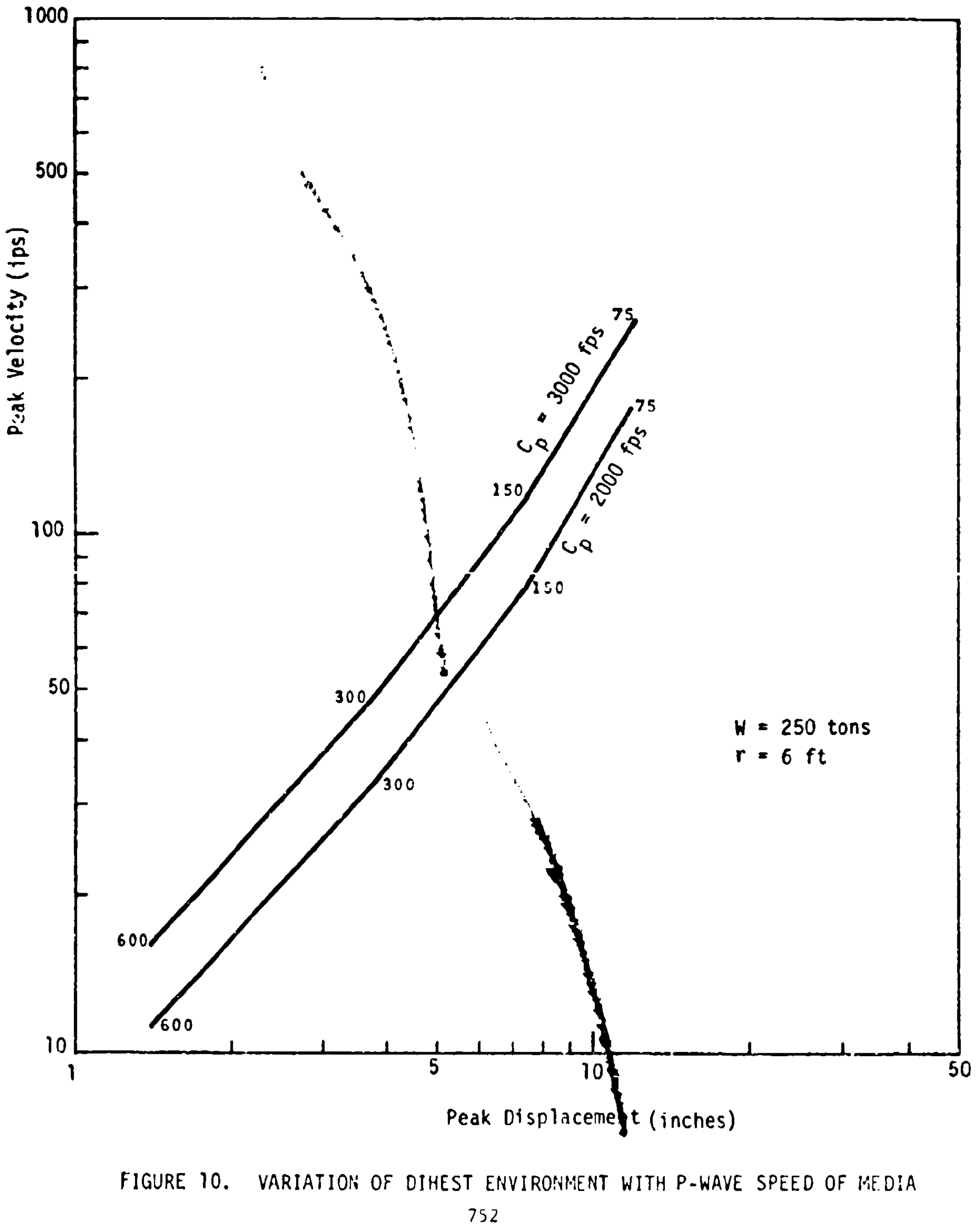
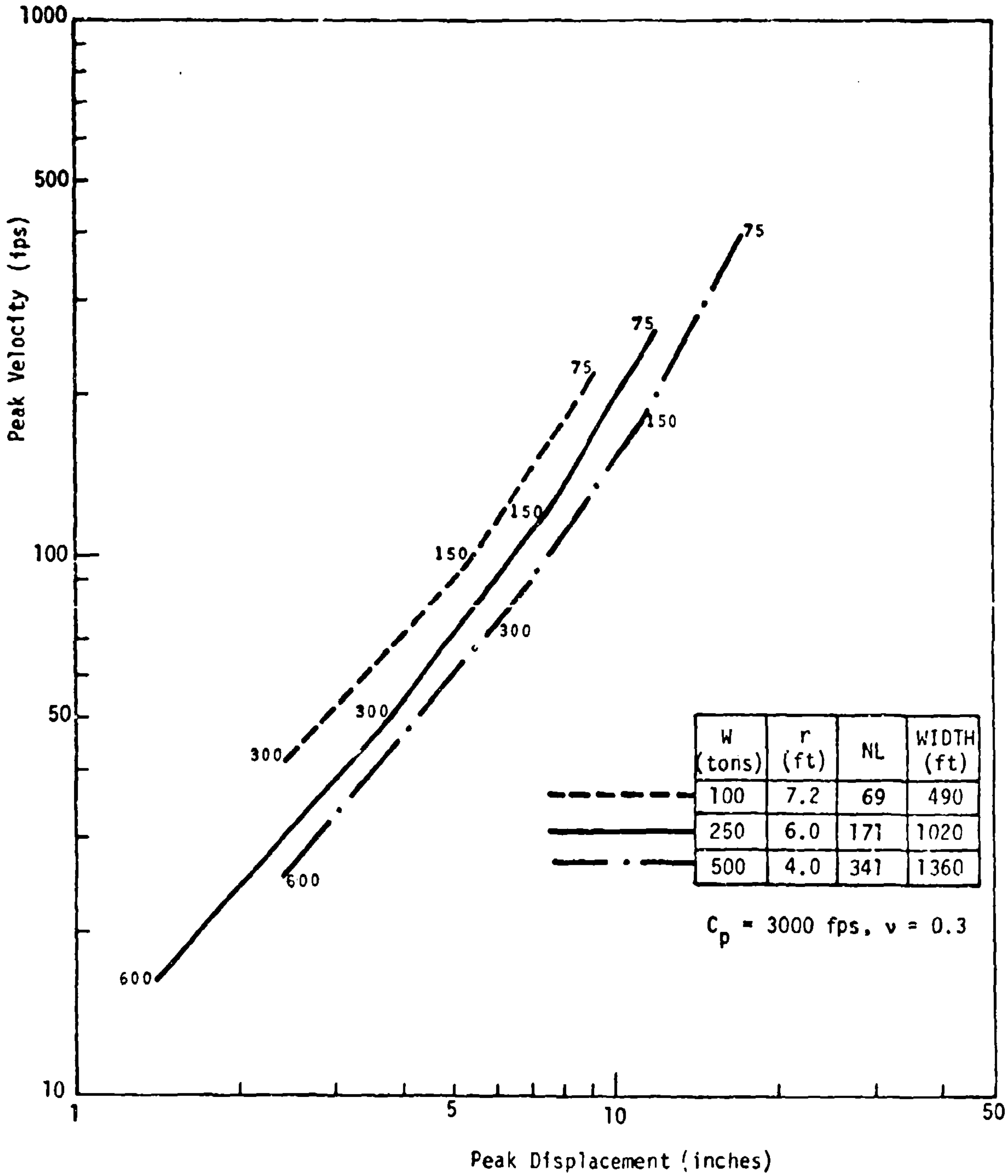


FIGURE 10. VARIATION OF DIHEST ENVIRONMENT WITH P-WAVE SPEED OF MEDIA



W (tons)	r (ft)	NL	WIDTH (ft)
100	7.2	69	490
250	6.0	171	1020
500	4.0	341	1360

$C_p = 3000$ fps, $\nu = 0.3$

FIGURE 11. VARIATION OF DIHEST ENVIRONMENT WITH TOTAL CHARGE YIELD

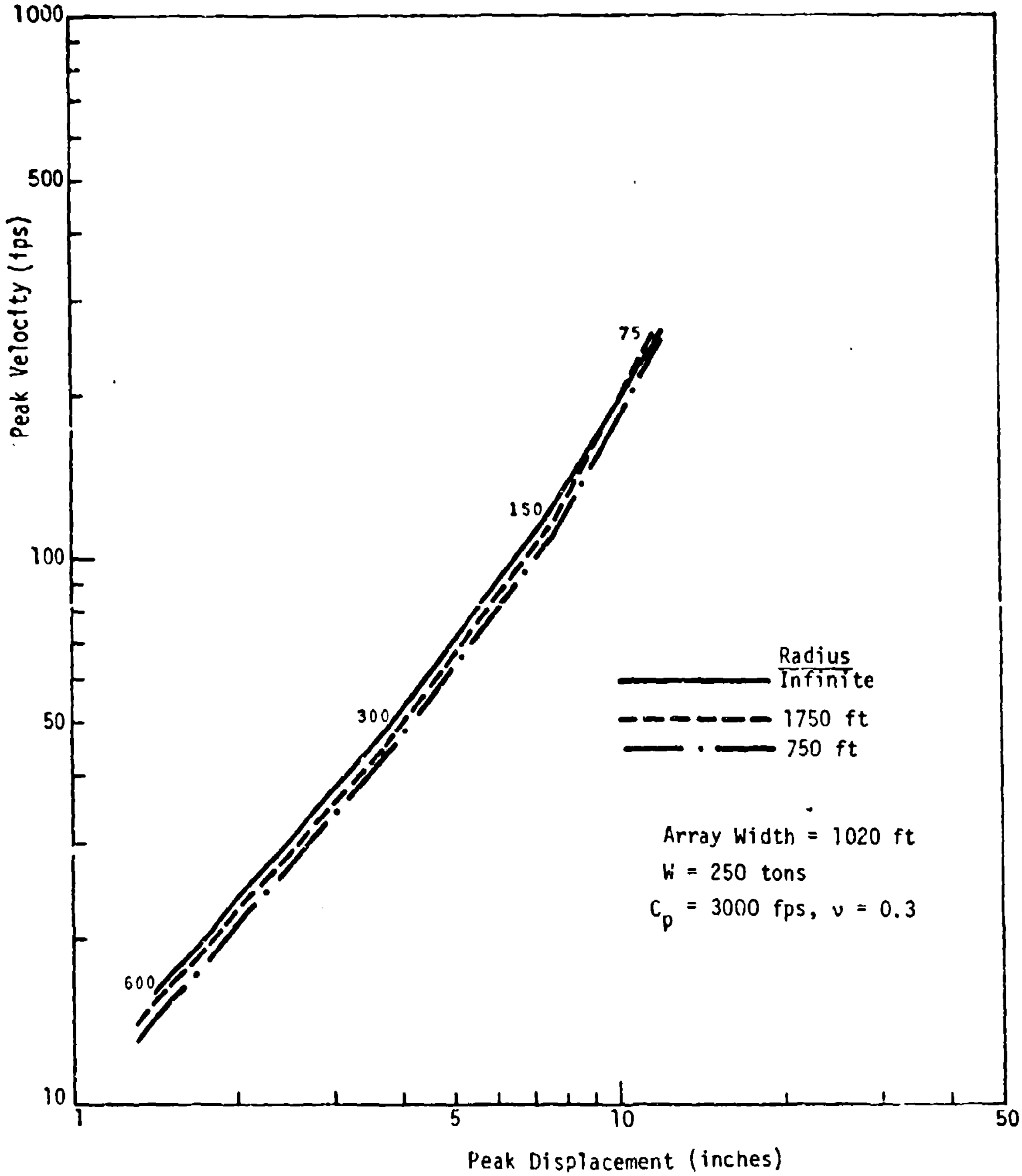


FIGURE 12. VARIATION OF DIHEST ENVIRONMENT WITH RADIUS OF CIRCULAR ARC ARRAY

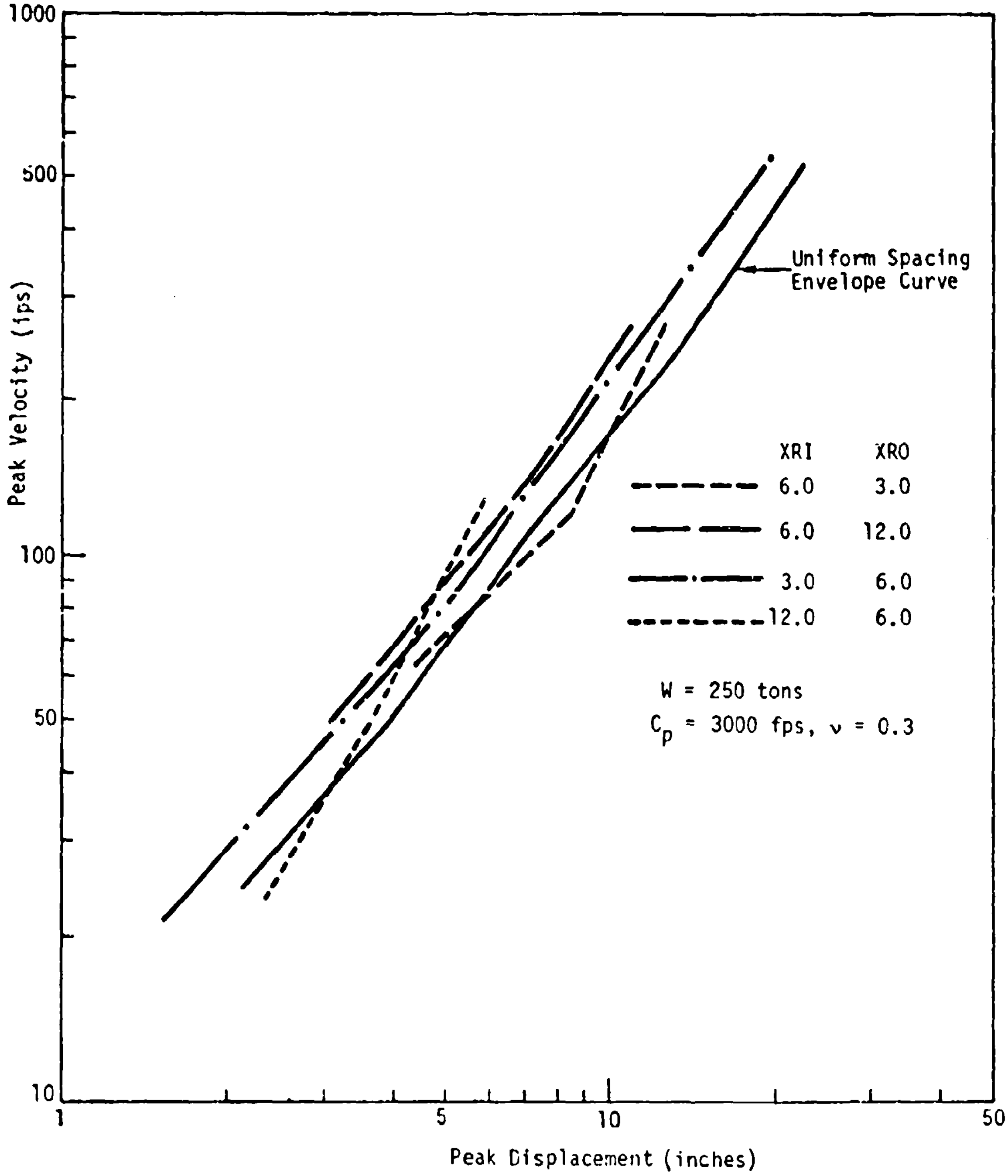


FIGURE 13. DIHEST ENVIRONMENT FOR VARIABLE SPACED ARRAYS

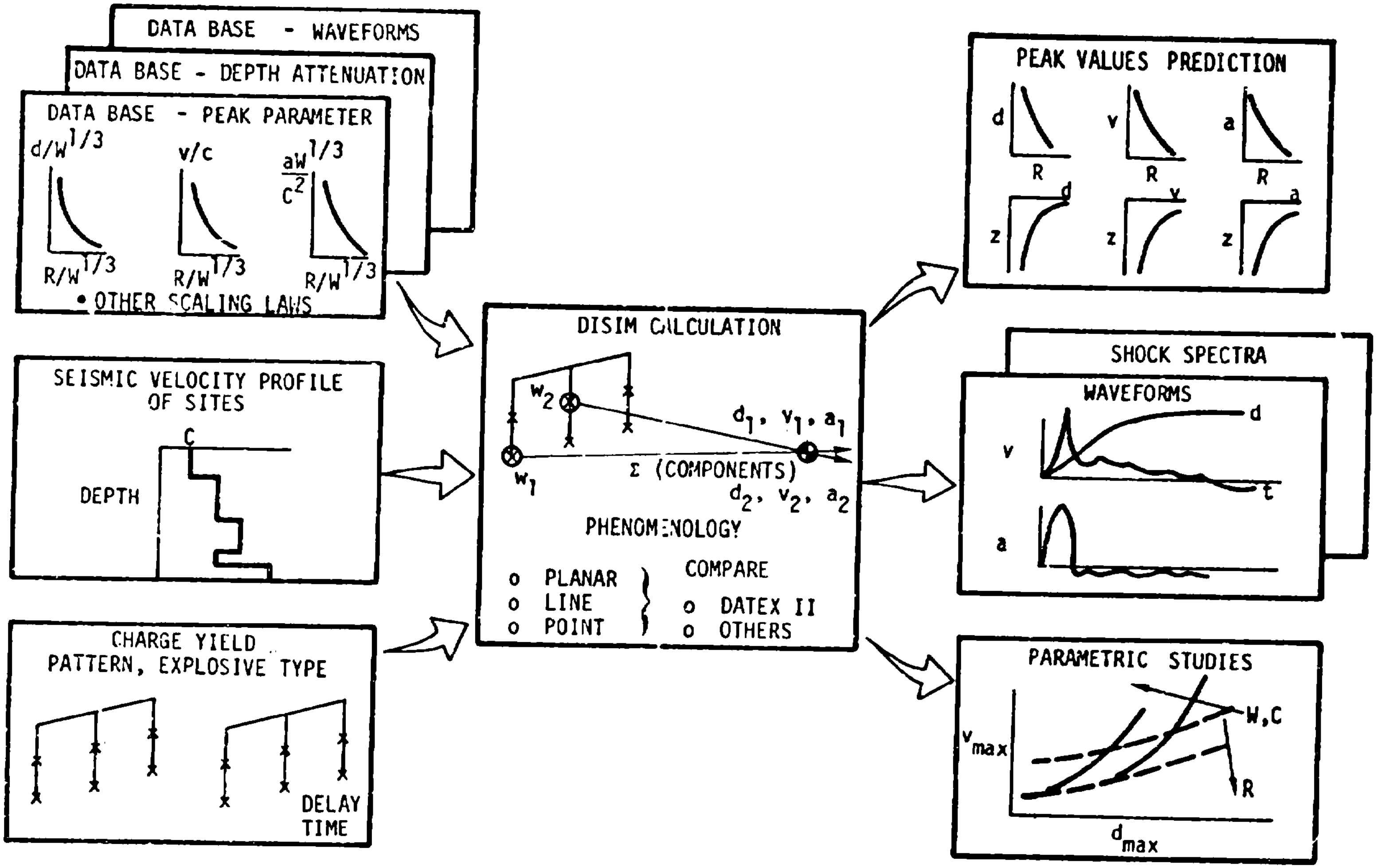


FIGURE 14. OVERVIEW OF THE DISIM METHODOLOGY